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OUTLOOK ON AGRICULTURE

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The design in linocut on the cover is a composite of drawings from two medieval manuscripts. In the centre is a figure from the works of Matthew Paris, who entered St. Alban's as a monk in 1217. Surrounding this, depicting farming activities throughout the year, are drawings based on MS. from the Benedictine Abbey of Sweifalten, circa 1162.

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SOIL FERTILITY IN THE TROPICS

Until a decade or so ago it was widely believed that the virgin soils of the humid tropics, with their great masses of vigorously growing jungle vegetation, were not only highly productive but had great reserves of fertility. Then agricultural scientists began to appreciate what planters and peasants had long known—that the appearance of high fertility was illusory; that once the jungle was cleared and crops were planted most of the land became exhausted within a few years. In fact, the jungle vegetation was largely maintained by a closed cycle of nutrient return, and when this cycle was broken the reserves in the soil were small.

This is only one of many misapprehensions that commonly exist, or have existed until recently, about fertility problems in tropical soils. Another is that the methods of cultivation and of fertility maintenance which have proved so successful in temperate climates can simply be transplanted to the tropics. Agricultural history is full of schemes for growing tropical crops that have failed, sooner or later, because of the naïve transfer of "modern" methods from cooler countries. Some methods have been transferred effectively, but usually a long period of experiment and of adaptation to the local conditions is required before success is possible. It is doubtless true that the fundamentals of soil science and plant nutrition are the same everywhere, yet in their working out and practical application there are vast differences in different climates.

Indeed, it is almost impossible to generalize about soil conditions in the tropics. There are major distinctions, all too easily forgotten, between the wet and the dry tropics in soils, vegetation, and plant nutrient supply; in savannah belts, with their moderate rainfall and sharply defined wet and dry seasons, the factors important in soil fertility once more behave differently; and yet again, the paddy soils in many respects are quite unlike soils from any of the dry-land areas. It is often stated, and with reason, that tropical soils tend to be strongly leached, acid, and deficient in available nutrients. Even in the humid regions, however, this does not always apply, while it may be far from true for the soils of the dry tropics, and the savannah soils, which are broadly intermediate, are highly variable in their nutrient status.

It is not surprising, therefore, that fertilizers vary greatly in their effectiveness in the tropical zone. With some crops—for example sugar cane, irrigated cotton, tea and bananas—large responses are generally obtained. With other crops, however, the responses are often disappointingly small, and the reasons for the poor effect, which may be many, are still being explored. Even where the soil is apparently deficient in available nutrients this does not necessarily mean a large response to fertilizers: other factors such as water supply, light intensity, length of day, poor inherent yielding capacity of the crop, low plant numbers, bad cultural methods, or pest or disease attack (any of which may operate more severely than in temperate climates) can limit crop growth. Further, tropical soils have a surprising ability to make plant foods available from their apparently limited store. Perennial plantation crops, with their longer life and greater root range, may behave quite differently in relation to nutrient supply from the largely peasant-grown annual crops.

Deficiencies of plant nutrients other than the NPK "trinity" are known to be important in some part of the tropics, and are likely to occur elsewhere. As Dr. Webb points out in this number (page 103), certain soils in West Africa are so lacking in one or more of the "minor" elements as to limit crop growth and prevent the common fertilizers from having their usual effects. When the missing element is added, then yields increase and so does fertilizer response. Nevertheless, most soils in the tropics have a supply of available minor elements sufficient for the crops that are grown, so that ordinary fertilizers are adequate. Minor or trace elements are not a panacea, but their deficiency is one of the more important factors that can restrict soil fertility and the responses to fertilizers in the tropical zone.

One of the most difficult things when studying tropical soils and their improvement is to hold the complexity of the whole situation in mind and to keep the various factors in proportion. What is true for dry-land crops and their soils in West Africa may not hold good for paddy soils in the Far East; methods that give remarkable results with sugar cane in Hawaii may have practically no application to shade-grown cacao in Trinidad —and so on. There are many good books on the science of soil fertility and manuring in temperate countries, the classic being Russell's *Soil Conditions and Plant Growth.* In the tropics, however, the science is still young, and the master book has yet to be written.

PROBLEMS OF FERTILIZER USE IN TROPICAL AGRICULTURE

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Problems in improving crop yields in the tropics are more complex than has hitherto been recognized, and different techniques from those used in temperate regions are needed to deal with them. Recent experiments show that deficiencies of minor elements in certain areas may account for the disappointing results given by fertilizers and the defective functioning of legumes, thus preventing the establishment of stable systems of farming.

INTRODUCTION

Over much of the tropical world the primary objective of farming is the direct production of the means of subsistence for the farmer and his family, and under the more primitive conditions the preoccupation is almost entirely with the cultivation of food crops. When production surplus to need is possible, crops can be harvested for export, permitting the importation of other goods and manufactured articles capable of contributing to an enhanced standard of living. Transport is a severe handicap and usually restricts the choice of an export crop to the more stable type of produce, such as cotton, cocoa, vegetable oil and oil seeds, tea and coffee. This dependence on single crops very often leads to a condition of economic insecurity where the national income is markedly affected by fluctuations in world market prices of staple commodities.

Standards of living can be raised only where production exceeds the basic needs of the grower, and the degree of improvement possible will depend upon the magnitude of the surplus and the efficiency with which it is produced. The surplus can be increased by extending the crop area without increasing the manpower required to the same extent, but with the primitive tools in common use in tropical agriculture the limit of physical effort is reached all too quickly, and in many parts of the world it is becoming difficult or even impossible to find suitable land. Sooner or later, and everywhere, the problem must be faced of meeting the needs of expanding populations in spite of dwindling land resources.

Greater efficiency of production, both in terms of manpower and land utilization, is needed now in many countries and will eventually be needed in almost all. It can be achieved in several ways. Animal or mechanical aids can greatly increase the area which one man can manage, but this is pointless where the land is limited in extent and the population has no alternative occupation to farming. Improved methods and systems of farming can, on the other hand, increase yields per acre without any notable increase in labour involved.

In temperate climates great strides have been made towards a high level of efficiency in crop production through the use of fertilizers. The world consumption of chemical fertilizers is now reckoned in terms of millions of tons of the elements nitrogen, phosphate and potash, and has more than doubled during the past ten years. Practically all of this is used in areas where agricultural systems are stabilized and developed and soil fertility can be maintained under conditions of continuous cropping, giving high crop yields and increased efficiency in the use of land and manpower.

Nothing comparable with the developed systems of temperate climates has evolved in tropical peasant agriculture to allow continued use of land under conditions of high yielding. There are, of course, many examples of continuous cultivation but generally without diversity of cropping. Land subject to periodic inundation is often kept in a monoculture of rice. Where flooding can be controlled other crops are often grown, but the continued success depends on periodic replenishment of nutrients carried as silt from elsewhere. Such tree crops as oilpalms, cocoa and coffee may occupy and protect the ground for extended periods, but the carrying capacity of the land in terms of human population is generally small. Sugar cane and cotton can often be grown continuously, but these do not represent a drain of essential nutrients provided that the crop residues are returned to the soil. Nevertheless the tendency is towards soil impoverishment, and the normal procedure is the ultimate, although temporary, abandonment of the land to natural regeneration.

Where a crop occupies land for an extended period attempts are frequently made to increase yields by the use of fertilizers. Over the greater part of the land in tropical areas, however, continued cropping of any one plot of land is not practised, and the use of fertilizers is rare. Where rainfall is sufficient for tree growth, the general pattern of agriculture is one of land clearance from forest or bush and cultivation for a period, followed by abandonment and reversion to bush when yields fall. Fresh forest or bush is then cleared for another period of cultivation. This, the "shifting system," in its most primitive form is practised where virgin forest is available for clearing; but this is becoming more and more uncommon, and the clearing of regenerated bush now occurs frequently. In some parts of the tropics the system has become in fact a long-term rotation in which a period of cultivation alternates with a more or less protracted period of rest during which there is a re-growth of bush. This system may be formalized, as in the "corridor system" of the Belgian Congo, where each demarcated strip of land, suitably orientated and of predetermined width, goes through its cycle of clearing, cultivation and recovery within a period of about 16 years, of which cropping occupies about 4 years. In the Gambia freshly cleared land is cultivated for 5–8 years and left for 15–20 years to recover to bush, but relationship of cropping period to the length of the full cycle is the same as in the corridor system—one-quarter. As long as this proportion is not exceeded the system can be operated indefinitely without deterioration of the soil. To cultivate a higher proportion reduces the period for recuperation and must in the end lead to a breakdown in the effectiveness of the system.

It would be unwise to assume that the shifting system is adopted solely because of ignorance of possible alternatives. Engledow [4] holds that it is practised only because other systems available to the farmer cannot maintain the level of production he requires. Until an alternative is found it is unreasonable to expect any sustained large increase in productivity. Large-scale clearing with the aid of machines has made increased production possible in several localities in Africa, but the higher level has not been maintained and land exhaustion has often been rapid. The thoroughness of clearing required for reasonable use of mechanical implements runs counter to the conditions favourable to rapid natural recovery. Except in very rare cases, therefore, the introduction of mechanical tillage is almost conditional on the introduction of a stable system of farming.

The problem, as far as Africa is concerned, was stated clearly by Hall in 1936 [6], and quoted recently by Willimott and Anthony [12]: "The first necessity in these agricultural communities of Africa is a change from shifting cultivation to fixed agriculture, to a recuperative system of farming which will maintain cultivation indefinitely on the same land." Except in special restricted situations, no solution has yet been found.

POSSIBILITY OF DEVISING AN IMPROVED SYSTEM OF AGRICULTURE

Systems capable of maintaining soil fertility through repetitions of a cycle of cultivations have been used for several thousand years. Those giving the highest productivity are arable systems under which, with proper management, the soil need not be impoverished. Indeed, in many countries of Europe the level of production has risen steadily, and in spite of very high yields the soil is far more fertile now than it was centuries ago.

Legumes have been the key to many successful farming systems, coupled in later years with the use of chemical fertilizers. In the tropics, however, the use of legumes has rarely led to an improved agricultural system, though there are exceptions. Pigeon pea has been used with success in India and is a means of keeping land in more or less continuous cultivation. The legume is grown as a permanent crop and cut for carrying to the cropped land as and when required. On the other hand, in the Sudan no benefit could be demonstrated from the use of this crop as a soil restorer. In many parts of Africa the groundnut is used as a cash crop, but there is no evidence that its continued cultivation in any way improves the soil. In the writer's experience in the Gambia three out of five legumes tested as green manures were inferior to or no better than chance weeds similarly treated. In contrast, Faulkner [5] reported that a legume crop (*Mucuna*), either turned in green or burned, maintained the yield of maize without diminution through seven repeated cycles. With a different legume, *Phaseolus lunatus*, it was found that the manurial value of the burned haulms, after harvesting the seed, was not inferior to that of *Mucuna* buried green. Thus, although legumes have not in general provided the key to successful rotation systems, they appear to be capable of doing so given suitable conditions.

This deficiency in function of legumes grown in tropical soils may be related to the paucity of nodules. Only rarely has the writer seen good nodulation on legume species in the Gambia, in spite of much searching. Masefield [9] has also observed that the nodulation of annual legumes is poorer in the tropics than in temperate climates. It might be inferred from this that nitrogen fixation by symbiosis proceeds at a reduced rate and that the contribution the legumes make to soil improvement is in consequence less than it should be. If the performance of legumes were improved it might be possible to devise a rotation system capable of maintaining or raising soil fertility under continuous cultivation.

The failure of legumes to acquire an adequate supply of nodules may be due to a lack in the soil of the necessary strain of symbiotic bacteria or to inimical nutritional conditions. Failure due to absence of the appropriate bacteria can occur in temperate countries, and soil inoculation with active strains is sometimes resorted to when new varieties of legumes are introduced, but there is little evidence that this explanation is of general applicability in the tropics. Most of the legumes do form nodules which appear to contain the haematin pigment associated with nitrogen fixation. It is the size and number of the nodules, and occasionally their position on the roots, which are the manifestation of the defect. This kind of defect seems more likely to be due to nutritional conditions than to other causes.

Many fertilizer trials in the tropics have not given the responses that might reasonably have been expected from experience in temperate climates. Usually attention has been restricted to fertilizers containing nitrogen, phosphorus and potassium, and the possibility of mineral deficiencies from other elements has been neglected although it is possible to point to responses to other elements in some areas. Conrad *et al.* [3] showed in California that sulphur fertilization of legumes could treble their yield and double that of the non-legume crop which followed. Anderson [1] in Australia showed that clover gave a large increase in yield with a dressing of molybdenum trioxide at 2 oz./acre in the presence of superphosphate, and an even greater increase in the presence of boron as well.

It was thought that mineral deficiencies other than N, P and K might be limiting in tropical soils, if not initially at least after a few years of cultivation, thus restricting the functioning of legumes and preventing the establishment of stable farming systems. The same deficiencies might also be responsible for the disappointing results obtained in many fertilizer trials of the past. A systematic and comprehensive investigation of mineral deficiencies of tropical soils might provide clues which would enable the obstacles preventing the introduction of developed systems of agriculture to be overcome. Even if this objective were not attained the results ought to show how the problem of increasing yields in tropical areas from the use of concentrated chemical fertilizers might be approached.

INVESTIGATING MINERAL DEFICIENCIES

In the light of modern knowledge of the particular elements necessary for satisfactory growth and reproduction of plants it is clearly taking too narrow a view of the problem to confine attention to nitrogen, phosphorus and potassium. Thirteen mineral elements are known to be essential for higher plants. Excluding carbon, hydrogen and oxygen, which are normally readily obtained from the air or are regularly replenished in the soil, the essential elements are nitrogen, sulphur, phosphorus, potassium, calcium, magnesium, iron, manganese, copper, zinc, boron, molybdenum, and chlorine. The first six are known as the major elements, being normally required in relatively large amounts. The remaining seven are referred to as the minor or trace elements, for they are required in much smaller amounts by plants, although the deficiency of any one of them is just as important to a plant as that of a major element. The element which can convey the greatest benefit to a plant is the one currently limiting its growth, and additional supplies of other elements will be largely superfluous.

It is not difficult to envisage a situation in which growth of a plant is restricted because of deficiencies in the supply of several essential nutrient elements. The deficiencies may be of different degrees of severity. Their effects on the plant are, of course, not additive. Growth will be restricted to an amount permitted by that element which is most severely deficient, and as far as the sub-optimal plant is concerned the other elements are not in fact currently deficient. They may become so when the primary limiting deficiency is corrected. In seeking to increase crop yields by the application of fertilizers the aim is not simply to detect and correct the primary limiting deficiency: it is to detect *all* deficiencies which are preventing optimum yields of the crop plants, and to correct them when this can be done profitably.

Techniques that work satisfactorily when single deficiencies only exist, may not be effective when several deficiencies occur. Diagnosis of deficiencies through the recognition of specific visual symptoms has been the subject of much work and there have been published many coloured illustrations, e.g. by Wallace [12]. The effect of multiple deficiencies on the appearance of plants has not yet received sufficient attention, and it is generally difficult to diagnose more than one deficiency from visual symptoms. The same difficulty exists with the technique of testing for a response to the application of any particular element. Provided other elements are not seriously deficient, a plant can be expected to show symptoms of its main deficiency and to respond in some way to the application of the deficient element. Both methods become misleading when multiple deficiencies occur, for absence of a specific deficiency symptom or failure to respond to a particular element cannot be taken as evidence that the element concerned is not lacking.

A more useful alternative technique appeared possible in the procedures described by Hewitt [9] for producing plants with known mineral deficiencies. Comparisons of plants grown in a substrate of purified sand and supplied with either a complete mineral nutrient solution or a solution lacking only one particular element show the effect, either on appearance or in other ways, of the specific deficiency. Application of this procedure to plants in soil seemed to offer hope of detecting soil deficiencies more speedily than by other means, with less work, and with greater certainty of avoiding complications due to multiple deficiencies. If, by withholding any given element from an otherwise complete nutrient mixture, the growth of the plant is reduced as compared with a plant receiving the complete nutrient mixture, it may be supposed that the soil is unable to supply enough of the omitted element for good growth. Fifteen tests—one for each of the thirteen essential elements, one with a complete nutrient mixture and one control with pure water—are sufficient to demonstrate all possible mineral deficiencies. The reduction in work is obvious. The degree of precision required is obtained by replication in the usual way.

THE SUBTRACTIVE METHOD OF DIAGNOSIS

The subtractive procedure was tested in the Gambia in 1954. At that time chlorine was not regarded as essential and so did not enter into the scheme. The requirement of plants for this element put it into the trace element group. The scheme operated deals with the remaining twelve essential elements.

Ideally, the method calls for facilities for producing nutrient solutions of known purity, for water of the highest purity, and for containers that will not introduce contamination to the soil they hold. The technique described by Hewitt was followed closely. For major element deficiencies chemicals of analytical grade were used. These were further purified for trace element deficiencies. Boron was removed by double or treble recrystallization of the major nutrient salts, manganese and iron by precipitation on calcium carbonate during autoclaving, copper and zinc by extraction with dithizone, and molybdenum by co-precipitation with copper sulphide. Each nutrient solution is, of course, only purified free from one element. The water was purified by multi-stage treatment in synthetic zeolite columns. The containers for soil were 11 in. earthenware plant pots coated inside with at least two coats of a bitumen preparation (Bituros solution).

The complete nutrient solution employed was that used by Hewitt [9]. It was known to give good results with most test plants when grown on purified sand. The composition was:

KNO_3	10·1 g.
$Ca(NO_3)_2$	16·4 g.
$NaH_2PO_4.2H_2O$	4·2 g.
$MgSO_4.7H_2O$	7·4 g.
Ferric citrate	0·5 g.
$MnSO_4.4H_2O$	44·6 mg.
$CuSO_4.4H_2O$	5·0 mg.
$ZnSO_4.7H_2O$	5·8 mg.
H_3BO_3	37·2 mg.
$(NH_4)_6Mo_7O_{24}.4H_2O$ ..	0·7 mg.

These amounts, dissolved in 20 litres of water, made the nutrient solution, which was applied at a rate of 1 litre per day per 11 in. pot of adult plants. The nutrient is most conveniently made up at 10 times strength and diluted as required.

The deficiency solutions were prepared by omitting each element in turn and making a suitable substitution, thus:

Omit N—replace KNO_3 by 8·7 g. K_2SO_4 and $Ca(NO_3)_2$ by 17·2 g. $CaSO_4.2H_2O$. At 10 times normal strength this is a suspension and not a solution.

Omit K—replace KNO_3 by 8·5 g. NaNO.

Omit P—replace $NaH_2PO_4.2H_2O$ by 4·2 g. $Na_2SO_4.10H_2O$.

Omit Ca—replace $Ca(NO_3)_2$ by 17·0 g. $NaNO_3$.
Omit Mg—replace $MgSO_4.7H_2O$ by 9·7 g. $Na_2SO_4.10H_2O$.
Omit S—replace $MgSO_4.7H_2O$ by 6·7 g. $MgCl_2.6H_2O$.

Ideally, all the trace elements should also be added as chlorides or nitrates instead of sulphates. This was not necessary in the work in the Gambia.

To omit the various trace elements first prepare the major element components, purified for the particular deficiency, and add to them the necessary trace elements, leaving out the appropriate element.

To study major element deficiencies the solutions were made up in water derived from a well. For deficiencies of Mn, Fe and B, water was purified by passing through five zeolite columns, Zeo-carb 215 (three columns) alternating with De-acidite E (two columns). For deficiencies of Cu, Zn and Mo, water was purified through the five columns and finally through a mixed-bed column of Biodeminrolit.

Soil was taken from the top foot of plots at different parts of the Experimental Farm, Yundum, in the Gambia. It was air dried, sieved through fabric mosquito netting and mixed thoroughly by quartering three or four times. The drain holes of the pots were covered by glass wool and pieces of glass to prevent loss of soil. A batch of pots for any test was filled by putting small portions of the soil into the pots in turn until finally all were filled. It was thought that this would give a more uniform distribution of soil than if each pot was filled completely before proceeding to the next one.

A variety of test plants was used in the initial trials, chosen mainly for their ability to produce symptoms characteristic of specific deficiencies—tomato, lettuce, lucerne, dwarf bean, cabbage, maize, green gram and groundnut. The soil in the pots was wetted with water of sufficient purity for the treatment intended, until drainage just began. Seed was sown directly into the soil with glass rods. After germination thinning was carried out as required and watering with nutrient solutions was begun. After the early trials it was found possible to reduce the frequency of application of nutrient from daily to alternate days, and in some experiments to once per week. In the intervening periods water of suitable purity was given. Loss of nutrients by over-watering to the extent of causing drainage was avoided, except for boron deficiency treatment. Since there was reason to suppose that B deficiency might be associated with particularly heavy rainfall, some of the pots were deliberately over-watered regularly with the Omit-B nutrient. In this way the "alfalfa yellows" of B deficiency in lucerne was produced.

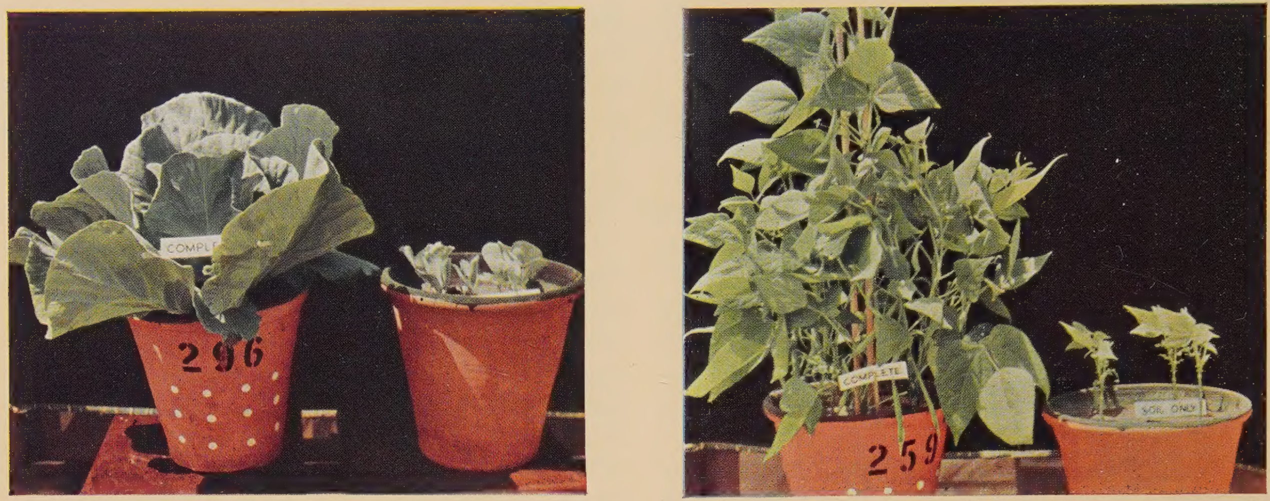
The effect of omission of the various elements from the nutrient solutions given to the test plants was very marked. The first comparisons were made between plants receiving the complete nutrient and those receiving only very pure water. Figure 1 shows pairs of pots containing plants, on the left supplied with complete nutrient, on the right with pure water only. Figure 1 shows in (*a*) cabbage plants at 90 days, and in (*b*) dwarf beans 54 days old. The difference between the two treatments is some measure of the improvement which is possible, given adequate mineral nutrition, and is a very good indication that there are mineral deficiencies in the soil.

The next stage is to determine what are the specific deficiencies which, separately or collectively, are responsible for the poor growth of the plants subsisting on the soil alone. The appearance of the plants gave no clear indication of what deficiencies were affecting their growth. However, by making comparisons between plants receiving the complete mineral nutrient and plants receiving the various deficient nutrients from which each in turn of the essential elements had been omitted, the particular deficiencies could be diagnosed. Some of these comparisons are shown in Figures 2 and 3, the plant with complete nutrient being on the left in each pair.

The effect of omission of N is exemplified by the group of diminutive cabbage plants shown in Figure 2(*a*) alongside the large plant which received the complete nutrient. Originally pale, the deficient leaves in age assume orange-red or purplish tints. There was some slight indication of the formation of red or purple tints on the leaves of the cabbage growing on soil only, but it would have been difficult to say from inspection whether the deficiency was of N, of P, or of both. The Omit-N test shows that the soil is deficient in N for the growth of cabbage.

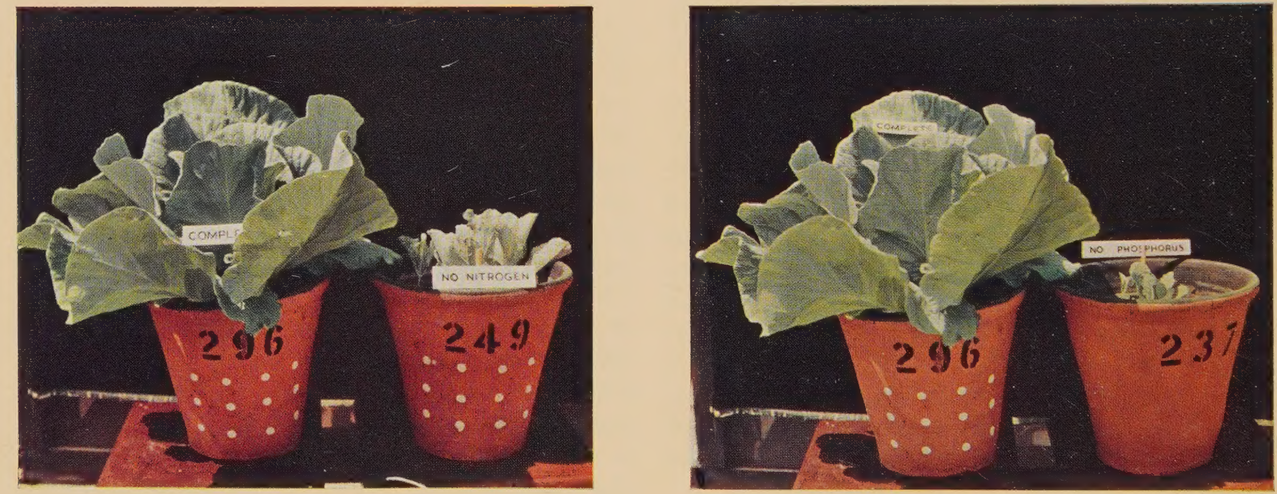
The effect of omission of P on cabbage is shown in Figure 2(*b*). Apart from the greatly reduced stature, the plants had the dull bluish-green tint normally associated with P deficiency.

Omission of K from the nutrient had little or no effect in the early stages of growth. Up to 40 days there was no visible difference between plants

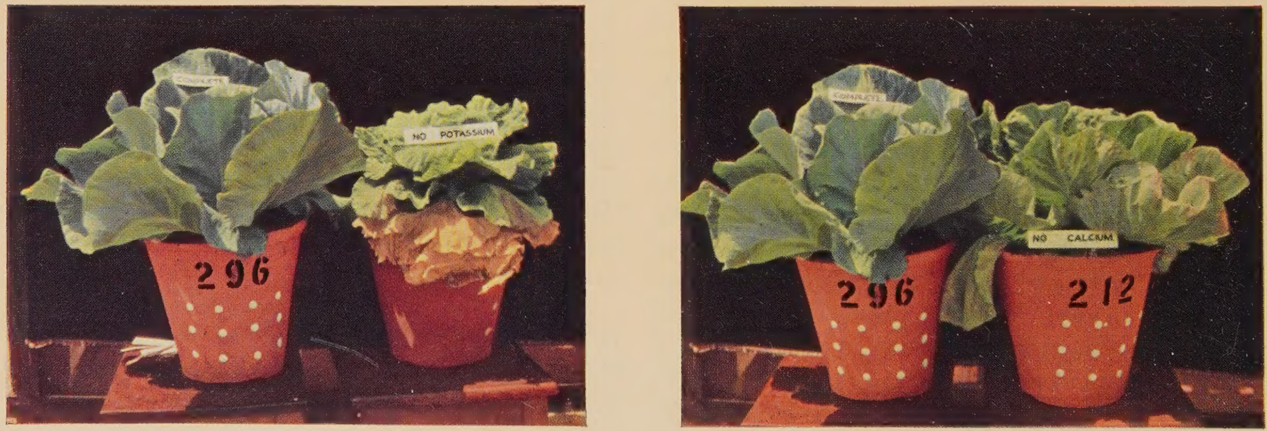


(a) (b)

FIG. 1 (*a*) and (*b*). (*a*) Cabbage and (*b*) dwarf bean plants grown on a Gambian soil with (left) complete nutrient and (right) pure water only.

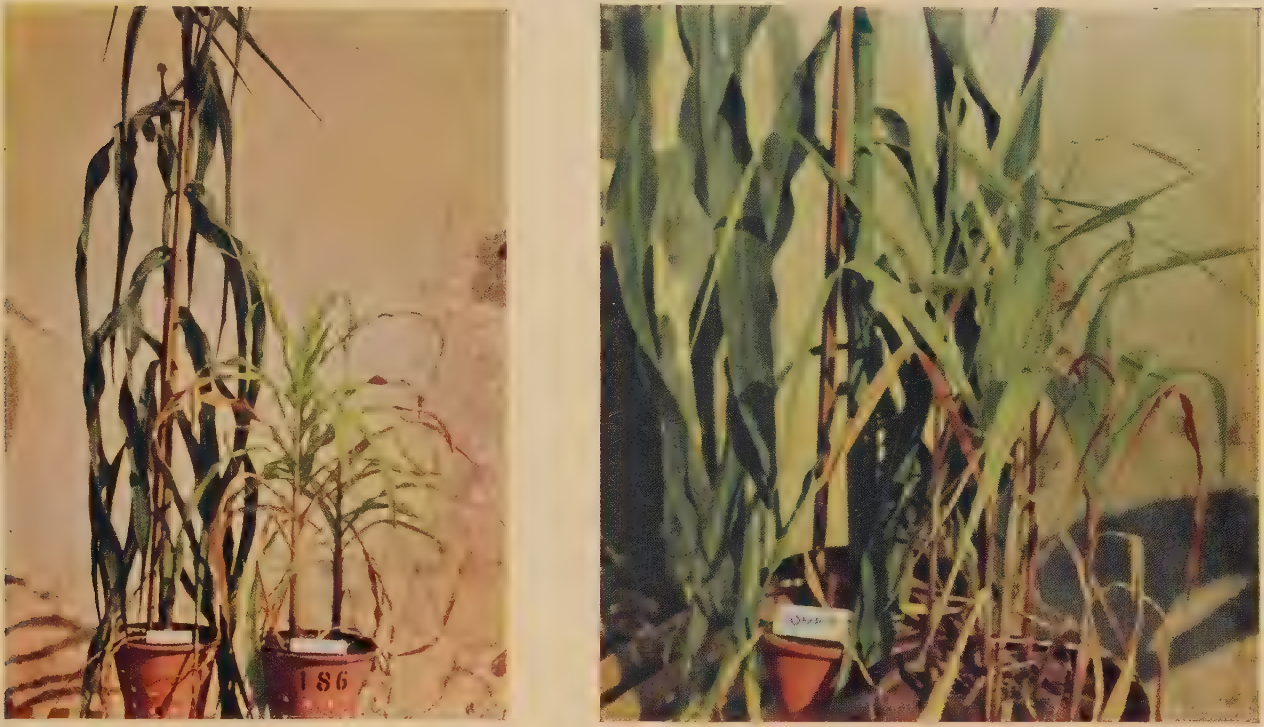


(*a*) Omit N (*b*) Omit P



(*c*) Omit K (*d*) Omit Ca

FIG. 2 (*a*)–(*d*). Effect of a specific mineral deficiency (N, P, K or Ca) on cabbage plants grown on a Gambian soil. In each illustration the plants on the left received a complete mineral nutrient.



(*a*) Omit S

(*b*) Omit Zn

FIG. 3 (*a*) and (*b*). Effect of omission of S or Zn from a complete nutrient solution given to maize plants grown on a Gambian soil. The control (complete nutrient) plants are shown on the left in (*a*) and in the background in (*b*).

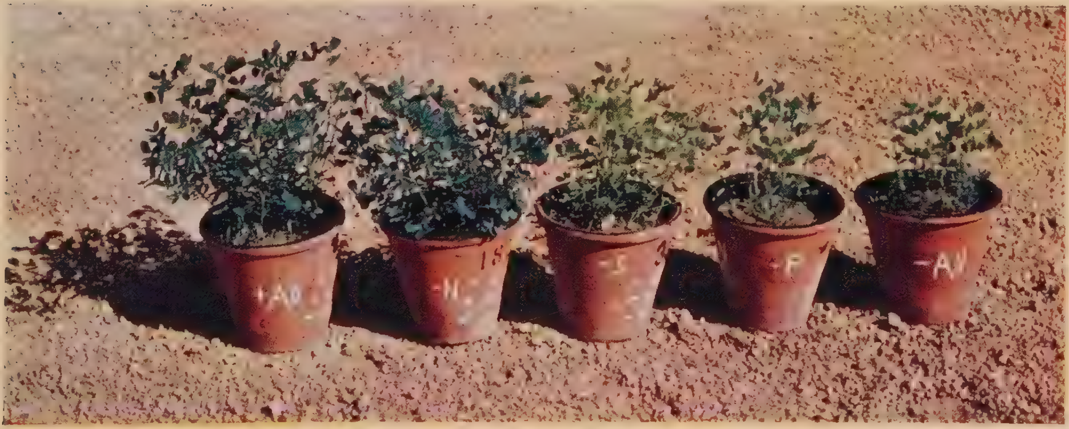
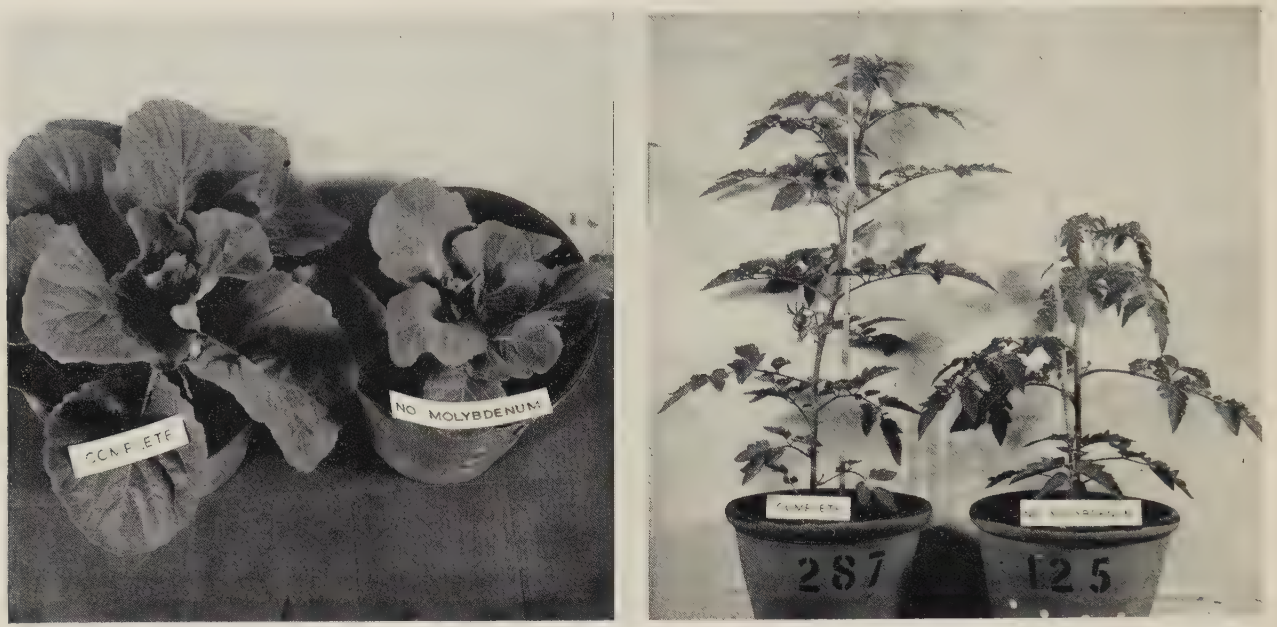


FIG. 4. Groundnut plants grown on the same Gambian soil supplied with (extreme left) a complete mineral nutrient and (extreme right) water only. The plants between these received the nutrient solution lacking only N, S and P respectively. (Note the negligible effect of omission of N, the paleness due to lack of S, and the marked dwarfing caused by S deficiency.)



(a) (b)

FIG. 5 (*a*) and (*b*). Effect on (*a*) cabbage and (*b*) tomato plants grown on a Gambian soil with (left) and without (right) molybdenum.

with and without K, as far as tomato, dwarf bean, cabbage and maize were concerned. After this period the lack of K began to show, and by 51 days the tomato plants lacking K were noticeably smaller than those with complete nutrient. This was true for maize and cabbage also. When fruiting began the tomato plants collapsed suddenly; over a period of only 10 days they changed from more or less normal plants, although shorter than those receiving the complete nutrient and showing slight marginal paleness, to scorched and dried-up plants with most of the leaves dead. Cabbage showed a similar collapse, the leaves paling, crinkling, and showing scorch on the older outer leaves, as illustrated in Figure 2(*c*) of a 90-day-old plant lacking K. Lack of K seems to stop the growth of the plant at about the stage of the first appearance of symptoms of K deficiency. Symptoms then become progressively more and more severe until scorching and final collapse occur.

In the early tests of the subtractive method of diagnosis, Ca deficiency was not often apparent, but it occurred in cabbage (Figure 2(*d*)) and once in tomato. It was observed more frequently in later tests on other soil samples.

The effect of lack of S was apparent on most of the test plants, taking the form of a general paleness and thinness of the leaves. Stunting was not always marked, although plants frequently looked thinner and less vigorous. Marked stunting occurred with maize on one of the soils, however, and this is shown in Figure 3(*a*). Here a maize plant receiving the complete nutrient mixture is contrasted with one of the same age which lacked only S.

Symptoms associated with lack of the trace elements were rather uncommon, perhaps because the deficiencies were less severe. A clear, visible effect of Zn deficiency appeared on one soil with maize as test crop. This is illustrated in Figure 3(*b*), where the short Zn-deficient plant, pale, with incurled leaf margins at the tips, reddened mid-rib and leaf bases, and scorched older leaves, is shown against a portion of the healthy complete nutrient plant of the same age grown on the same soil.

Absence of Mo from the nutrient solution did not produce any of the characteristic symptoms associated with the deficiency of this element, but there was a notable reduction in growth of cabbage, tomato, lucerne and lettuce. These reductions in growth are shown in Figure 5 of cabbage at 40 days and of tomato at 51 days, with and without Mo.

Most of the test plants used are indicators capable of showing characteristic symptoms when suffering from a specific mineral deficiency. To some extent it might also be said that they have particularly high requirements of certain elements. It is conceivable, therefore, that taken collectively they might present a picture of mineral deficiencies which is an exaggeration of the position as it affects crop plants normally grown on the soils being tested. That this is in part true can be seen in Figure 4, which shows on the extreme left a groundnut plant growing with a complete mineral nutrient supply and on the extreme right a plant growing in the same soil supplied with water only. The discrepancy in size is not so great as for tomato, cabbage, or dwarf bean under similar conditions, but the difference is large enough to lead to a conclusion that on this soil groundnuts could easily suffer from mineral deficiency. Between the outermost plants are inserted plants lacking only N, S, and P respectively. It will be seen that the omission of N has had little or no effect. This is important as showing that given adequate mineral nutrition the groundnut, a legume, can be self-sufficient for N on this soil. Lack of S produces an obvious diminution in size and a well-marked overall paleness. It has also been observed that on some of the Gambian soils tested with the Omit-S treatment the groundnut frequently fails to form nodules on its root. The plant is scarcely distinguishable from the one on the extreme right, which received water only.

PLANT WEIGHT AS A CRITERION OF DEFICIENCY

Use of the subtractive method, coupled with the recognition of specific deficiency symptoms, has revealed a state of multiple deficiency in some sample soils tested in the Gambia. This multiple deficiency could not readily be observed under normal growing conditions, but its detection is made possible by the elimination in each test of all deficiencies except the one sought. In general, where the omission from the complete nutrient mixture of any element has had an effect on the test plants, that effect has been firstly a reduction in size, often without the appearance of any characteristic symptom. When deficiency appeared to be more severe, in so far as the reduction in growth was greater, the symptoms characteristic of the specific deficiency generally appeared. Only once—S deficiency in tomato—were symptoms typical of a deficiency present without there being any noticeable reduction in growth. It seemed that, in the main, an objective assessment of deficiency could be made by recording the weight of the plant or crop produced under the experimental conditions and comparing weights of plants supplied with complete nutrient with those receiving deficiency treatments. This was done in some later trials and the figures obtained are given in Table I.

Chenery [2] has used a modification of the method in East Africa for the detection of soil deficiencies. The test plants are grown for only 5–6 weeks in small containers measuring 3 in. by 4½ in. with ⅜ in. drainage holes. They are lined with Alkathene film and hold about 400 g. soil.

TABLE I

WEIGHT (g.) OF VARIOUS PLANTS GROWN WITH COMPLETE NUTRIENT AND WITH NUTRIENT DEFICIENT IN EACH ELEMENT, ON GAMBIA SOIL

Treatment	Tomato plant at 28 days (dry)	Tomato plant at 46 days (dry)	Tomato plant at 60 days (dry)	Tomato fruit at 153 days (fresh)	Maize plant at 60 days (dry)	Cabbage plant at 120 days (fresh)	Groundnut plant at 150 days (dry)	Lettuce plant at 120 days (fresh)	Dwarf bean seed (dry)
Complete ..	1·30	12·74	41·0	1,046	80·0	970	131	522	56·0
Omit N	0·31 (s)	0·69 (a)	2·3 (a)	15 (a)	5·3 (a)	17 (a)	162	—	—
Omit P	0·025 (a)	0·10 (a)	1·0 (a)	0 (a)	5·6 (a)	15 (a)	0 (a)	—	6·2 (s)
Omit K	0·99 (m)	6·17 (s)	23·0 (m)	255 (s)	25·7 (s)	463 (s)	82 (m)	—	31·6 (m)
Omit Ca	1·33	9·10 (m)	45·0	1,176	49·2 (m)	932	58 (s)	—	—
Omit Mg ..	1·28	12·78	37·5	886	57·0 (m)	1,272	72 (m)	—	47·1
Omit S	0·53 (s)	9·77 (m)	48·5	727 (m)	—	—	65 (s)	—	56·5
Omit B	1·33	9·61 (m)	39·0	1,091	84·2	—	116	—	56·5
Omit Mn ..	0·23 (s)	8·66 (m)	44·5	1,111	59·2 (m)	664 (m)	114	—	51·6
Omit Cu	1·12	12·84	—	1,152	41·5 (m)	1,015	146	—	40·8 (m)
Omit Zn	1·26	7·46 (m)	—	911	51·5 (m)	956	155	—	57·3
Omit Mo ..	1·49	8·39 (m)	—	1,059	—	678 (m)	155	88·6 (s)	—
Control	—	—	1·0	0	4·6	3·7	62	4·2	6·2

(a) = acute. (s) = severe. (m) = moderate.

The reduced quantity of soil makes the method more convenient for routine testing but probably introduces a tendency to exaggerate any deficiency. This is not considered to be a serious disadvantage—it is certainly to be preferred to any tendency to minimize the effect of deficiencies. Other modifications are an overall application of $NaNO_3$ (except to controls and the Omit-N treatment) to avoid N-deficiency symptoms which tend to occur on the soils Chenery used. The effect of increasing the N in the complete nutrient formula has not been investigated. It is possible that a formula with more N might be better. With tomato as test plant, Chenery found it necessary sometimes to lime the soil up to *p*H 5·0 before reasonable growth was obtained. With soya bean as test plant this was not necessary.

After 5 or 6 weeks' growth, the aerial portions of the plants are harvested, dried and weighed. Dry weights are expressed as percentages of the weight of the plant grown with complete nutrient. An arbitrary scale of deficiency has been adopted: *Acute* being indicated by weights from 0 to 10% of the complete nutrient plants, *Severe* by 11–50%, and *Moderate* by 51–80%. Some of Chenery's figures for three different soils are quoted in Table II. The figures show N and S as *Acute* (*a*) or *Severe* (*s*) deficiencies, and three or four other elements in the range classed as *Moderate* (*m*) deficiency.

The application of this method of diagnosis, called the Subtractive Technique [11], has shown that multiple deficiencies ought to be regarded as a distinct possibility in any unknown situation.

TABLE II

SCALE OF MINERAL DEFICIENCY ON THREE DIFFERENT SOILS

(Data from Chenery [2])

Treatment	Bugusege	Sipi	Mutufu
Complete	100	100	100
Water only	4·6	11·2	0·16
Omit N	5·0 (a)	8·2 (a)	3·6 (a)
Omit P	82	88	95
Omit K	83	117	108
Omit S	30 (s)	32 (s)	0·44 (a)
Omit Ca	50 (s)	80 (m)	51 (m)
Omit Mg	84	110	97
Omit Mn	78 (m)	113	100
Omit Mo	96	76 (m)	64 (m)
Omit Cu	74 (m)	57 (m)	78 (m)
Omit B	88	98	87
Omit Zn	79 (m)	18 (s)	58 (m)
Omit Mn, Mo, Cu, B, and Zn	78 (m)	62 (m)	58 (m)

(a) = acute. (s) = severe. (m) = moderate.

APPLICATION OF THE METHOD AND RESULTS IN THE FIELD

Extending the method from pot tests to the field must introduce some modifications, for it is not feasible to employ pure chemicals as fertilizers in field trials. The use of impure fertilizer chemicals is no disadvantage with the major elements but could produce misleading results where the trace elements are concerned. Partial trace element deficiencies might readily be corrected by impurities present in the major element components of a fertilizer. This is of no particular importance provided the particular major element component is always uniformly contaminated and is normally included in the fertilizer mixture in its own right. To include a major element component in a fertilizer solely for its trace element impurity would be hard to justify on economic grounds. By the same token, it is of value to know just what elements are being effective in the nutrients supplied. Sulphur as a nutrient element is often confounded with N in ammonium sulphate, with K in potassium sulphate, and with P in superphosphate, and is all too frequently overlooked. In soils where S is the main deficiency addition of gypsum is probably one of the cheapest ways of supplementing the supply. The subtractive approach would indicate whether it was necessary to supply both N and S, or K and S, or Ca, P, and S.

The subtractive method has been used in field trials, but has not had the clear-cut outcome that pot tests have given. Results with the major elements have been essentially the same as were given with similar soil in the pot tests, but the trace element results were inconsistent. There was evidence that the application of trace elements should not be made at the same level as was used in the pot tests. The field tests were made in the Gambia, where leaching of nutrients is quite a serious risk. Application of trace elements in the same proportions to major elements as were used in the pot tests produced no definite effect. Much higher doses, as commonly used in temperate climates where trace element deficiencies exist, were sometimes toxic. The level of trace elements for field trials may need separate investigation.

Whether soil deficiences are diagnosed in the field, or results of the easier and more precise pot tests are taken as indications of probable deficiencies, the final step of finding the best fertilizer mixture for the situation must be a field trial. The customary method of determining the relative proportions of components required in a fertilizer mixture is to use the factorial design, in which two or more components, at two or more levels of application, are tested separately and combined in all possible arrangements. The design is capable of dealing with a situation where there are multiple deficiencies, but the amount of work involved becomes very large. When three elements are known or expected to be lacking, the simplest form of factorial trial involving two levels of application (excluding the zero level) requires a total of 27 treatments, at least in duplicate if the triple interaction is, as it may well be, the main response. Four elements call for 81 treatments. Where deficiencies are few the factorial method is an obvious choice of experimental design and has worked well. Some other approach is needed for three or more deficiencies.

Homès [8] has shown that it may not be necessary to investigate fertilizer requirements solely by the factorial method. His approach, the Method of Systematic Variations, is based on the fact that it is possible to group the major elements into two similar groups, anions and cations: N, S, and P on the one hand and K, Ca, and Mg on the other. In the exposition of the method it is shown that for any given total dressing there exists a best proportion for the ratio of N, S, and P, and another for K, Ca, and Mg. There is also a best ratio of total anions to total cations. The combination of these three proportions in one fertilizer gives the best mixture for the situation tested.*

Perhaps the most important part of the method is the claim that the best proportions in the two groups, anionic and cationic, can be calculated from the results of a trial involving only six mixtures of the elements in arbitrary proportions. The satisfactory application of the method of systematic variations to situations with multiple deficiencies will reduce the work required to determine the fertilizer mixture to a small fraction of that called for by the factorial design of trials. All the major element deficiencies are catered for, at a given total level of fertilizer application, by the six mixtures of the Homès's trial. In the factorial design six mixtures do not suffice for even two deficient elements at three levels of application.

Pot tests in the Gambia, using tomatoes and groundnuts as test plants, have shown that the claims made for the method are substantially upheld. It has been possible to compare a large number of responses obtained with many different fertilizer mixtures and so to determine which was in fact the best mixture for the conditions of the test. The formula of the observed best mixture was compared with the formula calculated from the results with the arbitrary mixtures used in the restricted Homès's trial. The agreement has generally been good, particularly when variations in composition have a marked effect on growth or yield, but has been less close where large variations in fertilizer composition appear to have little or no effect on yield.

The method of systematic variations does not take the trace elements into account, and it is necessary to ensure in the trials that serious deficiencies in this group do not interfere with the responses. Taken together, the subtractive method and the method of systematic variations appear to offer hope of a more satisfactory evaluation of fertilizer requirements than has been possible in the past in tropical agriculture. They may thus point the way to the introduction of stabilized agricultural systems on which the well-being, prosperity, and advancement of many populations depends.

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*Homès's method has been criticized, but the author is satisfied as to its usefulness, and at a later date he hopes to publish the results of experimental work using this method.

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EFFECTS OF DISEASES ON CROP PLANTS

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In studying the effects of diseases on crop plants more attention must be paid to the host than it usually receives. The green plant is able to compensate for damage to its organs, and a quantitative estimate of this action is essential to rational interpretation of economic losses from disease. Work in this field is progressing, and results of practical importance have been obtained by the artificial defoliation of plants and other techniques.

Crop disease is not merely the production of damage on a relatively passive host plant by a vigorous parasite; it is a nicely balanced struggle between the two, and only by studying their interactions can damage by disease be assessed at its true value and finally be controlled economically. A considerable amount of experimental work on the relations between crop hosts and their parasites under conditions in the west of Scotland has been carried out at Auchincruive during the past ten years, and this paper discusses some of the results of practical value that have been obtained.

There has been a tacit assumption that some loss is bound to occur when a parasite attacks a plant, but this is by no means always so. A classical instance of a disease actually enhancing value is to be found in the fantastic prices paid for "broken" tulips in the seventeenth century. We now know that they were only ordinary tulips naturally infected with a virus disease, yet tulips indistinguishable from the "broken" kind are still listed in catalogues at prices about 25% above normal. In contrast must be placed such diseases as potato root eelworm, which has already begun to eliminate a good deal of rich land from potato cultivation. Between these extremes is a variety of disease significance which clamours for more exact specification. There is great need for the sheer common sense of Ordish [12], who has also made a wide survey [11] to draw attention to this urgent problem. This has been ably supplemented by Padwick [14], particularly for the Colonies.

APPROACH TO DISEASE ASSESSMENT

Advisory experience at Auchincruive has suggested a classification of disease, for the estimation of real loss, into three main categories of damage:

1. Where the whole plant is killed, damaged or debilitated. This generally occurs when the parasite is present throughout growth, as in systemic virus diseases and soil-borne infections, or when an infection occurs at some strategic point, e.g. low on a main stem, or if there is "action at a distance," e.g. from toxins produced by the parasite.
2. Where only localized parts of a plant (or crop) are infected by the parasite, e.g. leaf spots, rust diseases, flower diseases, and diseases that thin the braird (seedling stand).
3. Where the effects of a disease outbreak are spread over more than one season, e.g. potato root eelworm and wart disease, which persist in the soil for long periods of time. Trees and long-term crops damaged as under (1) may also come into this category, since the replacement of killed trees means a loss of production for more than one season.

This is purely a grouping for convenience of assessment of damage, and a particular disease may cause damage in more than one category. Potato blight, for instance, is in category 1 as it attacks the tubers, but is in category 2 as it attacks the leaves.

The first requisite for the estimation of disease losses is to find the amount of disease present on a plant (severity) or crop (intensity) or region (prevalence). There are various standard area diagrams or keys for the estimation of severity or intensity, or both [1, 4], and various correct ways of obtaining average values [5]. Many surveys have been carried out over several years in Britain, the Continent and the U.S.A.

A logical counterpart of wide surveys is to establish a range of varieties of several crops over a period of years at one centre. Such disease phenology plots have been maintained at Auchincruive since 1944 and provide long-term assessments. We have found, for example, that under local conditions the spectacular chocolate spot disease of beans has had negligible effect on yield, whereas tuber blight on potatoes when uncontrolled has averaged 25% loss—much greater than had been realized. The problem is to relate the amount of disease to its actual effect on yield.

Yield Loss Factor

Numerous estimations of the yields of individual plants infected with diseases of category 1 reveal a rather surprising uniformity in the degree of debility. It is, indeed, feasible to express this as a numerical factor of 1·0 (for killing) or less (for debility), and then multiply the percentage of disease by this factor to obtain the crop loss. Alternatively, straight-line diagrams can be drawn to show the direct relation (Figure 1). The factors or graphs can be varied to meet particular requirements; those of Figure 1 are for total yield, and for many diseases this is the operative value. The 20% of grain yield produced by oat plants infested with tulip-root eelworms, for example, is useful produce, though it is rather lighter and has slightly less carbohydrate than grain from healthy plants; but it may lower the grade, and this effect is best dealt with by means of another factor concerned with market value [5]. On the other hand, potato blackleg leaves only 10% of the tubers produced by a healthy plant; these are unmarketable as ware or seed, and, unless there is a use for chats, the line in Figure 1 should be in the position shown for "tuber blight of potatoes," i.e. 100% loss on each affected plant, or a factor of 1·0.

Few diseases in Britain kill the whole plant, but Padwick [13] has mentioned several that occur in the Colonies. These would all have a yield loss factor of 1·0, though there would be an additional factor (>1·0) for replacement if the plants were trees. As shown in Figure 1, the loss of yield caused by most debilitating diseases is usually considerably less than the amount of disease.

SIMULATION OF DAMAGE

Localized attacks (category 2) may occur on the crop, or on the plant roots, leaves or flowers. The parasite is not usually present throughout growth, and there is frequently an important time factor about its first appearance. Calculation of loss from this kind of disease is rather more complicated than for the first type, and one of the best ways of getting useful knowledge is to simulate the type of damage. The effect of leaf damage can, for example, be studied by quantitative defoliation, and although such an operation is not absolutely comparable to damage by disease there are many instances in which the technique does enable us to gain some experimental insight into this important problem. Miller *et al.* [10] published detailed results of such a study in 1948, and found that artificial defoliation of wheat could indicate the loss in yield resulting from rust attack and hail injury.

Loss of Crop, Roots and Flowers

Damage to a crop by diseases that thin the braird can be simulated directly by sowing seed at different rates and comparing yield with the number of plants actually established per unit area (Figure 2). There is a distinct optimum plant density for maximum yield of barley, and doubtless for oats, though it was not revealed even by inordinately high seed rates in our experiments. The bean crop has rather a different relation, for yield does not seem to be affected by seeding at a rate above a certain minimum; any reduction of braird above this minimum would therefore have little effect on yield, whereas reducing the number of barley plants in a field above the optimum density would actually increase the yield.

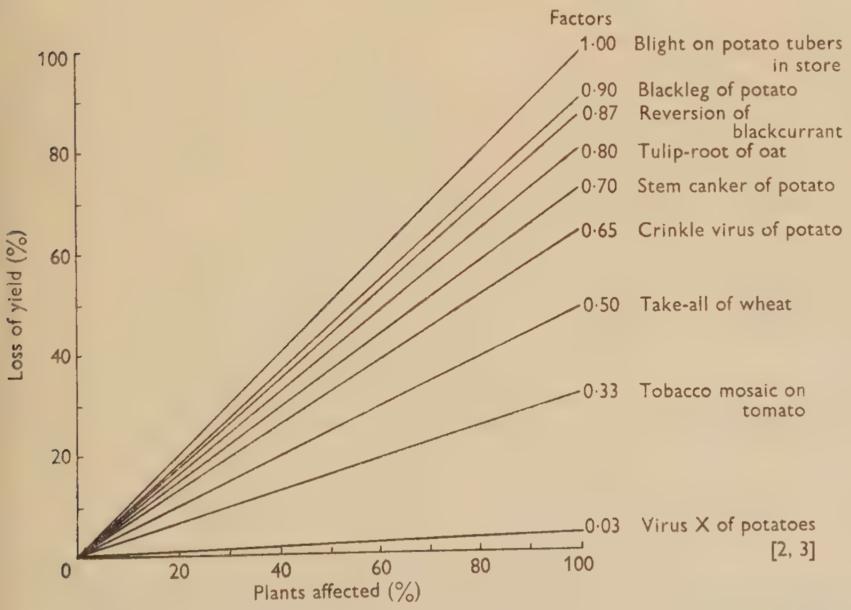

FIG. 1. Relations between the percentage of diseased plants in a crop (disease intensity) and total yield, for diseases that kill or debilitate the whole plant.

Losses of braird below the optimum plant density are similar in all three crops and are typified by the exponential curve of Figure 3A. This means that for a given percentage loss of plants there will be a lower

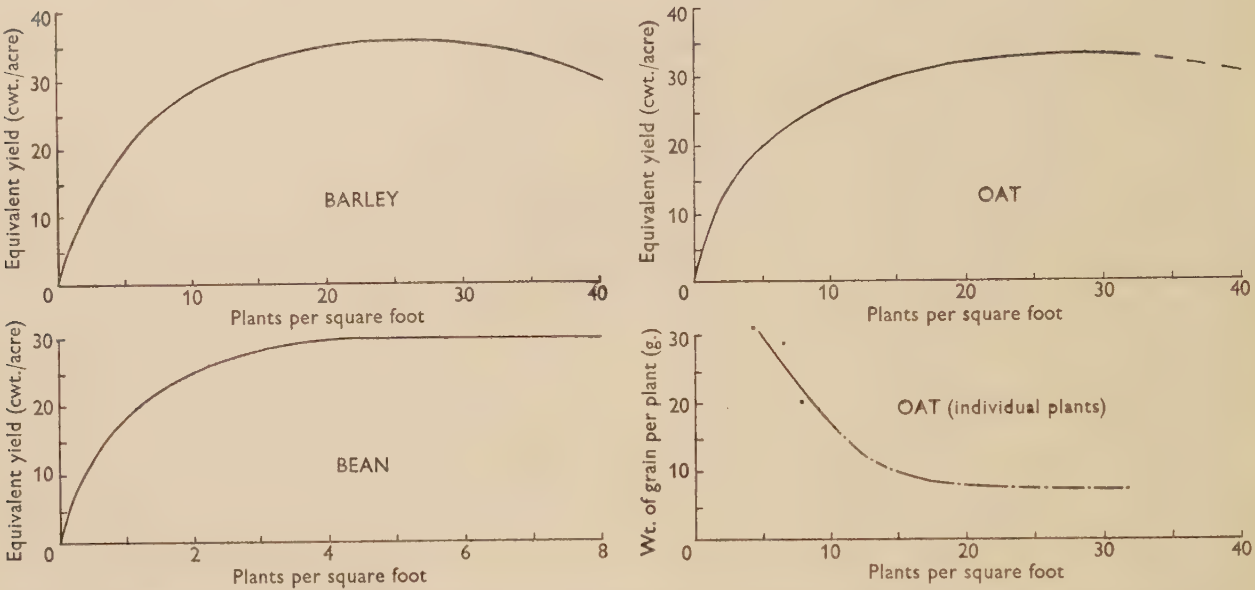

FIG. 2. Smoothed curves showing the general relations between plant density and yield, with individual plant yields for the oat.

percentage loss in yield of grain, except for the particular case when 100% plants are lost. The crop compensates for loss of plants, for those which remain have a higher yield per individual plant because of reduced competition and so tend to make up the yield (Figure 2, lower diagram). The decline in yield of the barley crop after the optimum stand has been attained is occasioned by the progressively acute competition with increasing plant density.

Loss of roots is difficult to contrive on a field scale, and the relations shown in Figure 3B for turnips and swedes were brought about by actual destruction of the true roots by club-root disease. The relation is linear for turnips, i.e. the percentage loss of roots is always equal to the percentage loss in yield. Swedes show a slightly exponential "toe," but above 40% loss of roots the relation is again linear; there is thus a small amount of compensation in the swede, but none in the turnip. Preliminary studies with potato root eelworm also suggest that the reduction of tuber yield is directly proportional to the percentage reduction of roots, at least in the early and middle stages of growth. It would therefore seem from these preliminary indications that plants might be less able to do without their roots

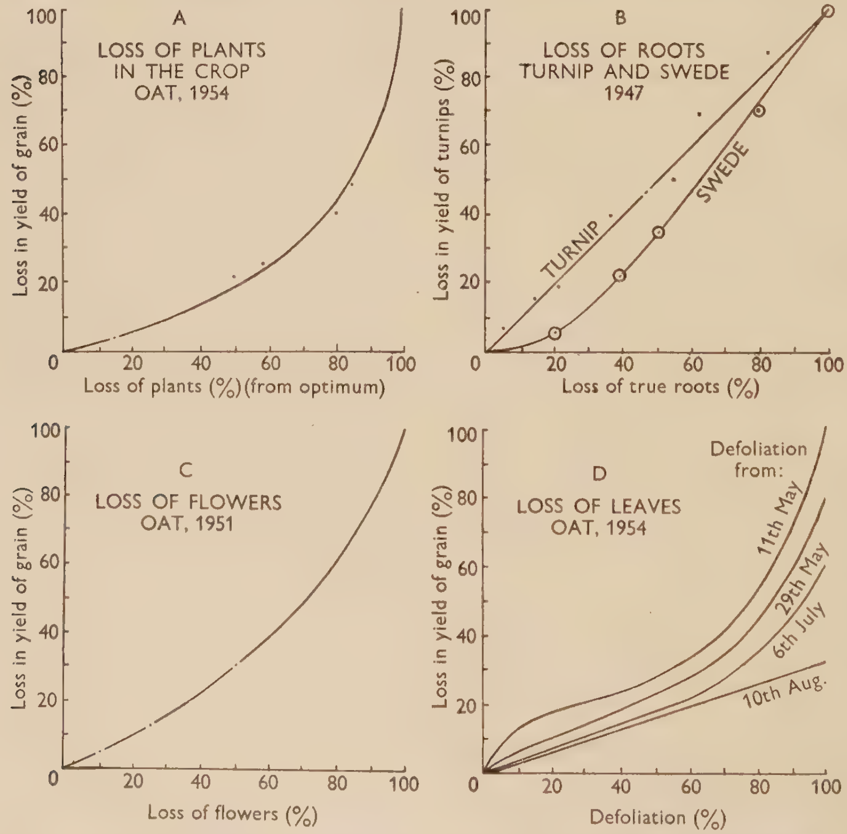

FIG. 3. Relations of losses of plants from the crop (A) and losses of plant organs (B, C, D) with yields.

than any other organ; the view is rendered likely by the very small amounts of dry weight which practically all plants expend on their roots.

The effect of loss of flowers can be studied by cutting off known proportions of the inflorescences as soon as they appear. In oats the principal cause of such losses in the field is the non-parasitic condition known as "blind ears." The relation to percentage loss in yield is again exponential (Figure 3C); the remaining flowers receive, individually, greater quantities of food to store in the developing fruits.

Loss of Leaves

Loss of leaves can be simulated by direct quantitative defoliation: a given proportion of foliage is removed at a particular date, and this proportion is maintained by frequent trimming throughout the remainder of growth. It is necessary, in order to get a complete picture, to begin defoliation at a number of dates through the growth cycle, when results like those for oats shown in Figure 3D are obtained. The first curve, for defoliation from 11th May is S-shaped or sigmoidal—a rather new relation in this work. It means that the lower percentages of defoliation (0–16%) cause a greater percentage loss of yield, but with 17–99% defoliation the relation is the compensating, exponential one, 100% defoliation causing total loss of yield. It is thought that the sigmoidal relation denotes a combined action of two factors, one of which might well be "wound shock," and the other the usual compensating factor where the remaining parts of leaves, and probably also the stems, photosynthesize relatively more efficiently than do normal, whole leaves. Defoliation from 29th May and 6th July are progressively less sigmoidal and more truly exponential, with even 100% defoliation causing 82% and 62% loss of yield respectively. Finally, there is the interesting linear relation of defoliation from 10th August—only seven days before harvest.

The reason for this relatively large effect so near to harvest is revealed by growth cycle analyses. For this purpose plants were dug at intervals through the whole cycle of growth, separated into their various organs, weighed, dried, weighed again, and stored for analysis; total carbohydrate (and its fractions when necessary), nitrogen and ash were then estimated. Results from the oat show (Figure 4) that there is a migration of carbohydrate and nitrogen, though not of ash, from the rest of the plant to the developing grain.

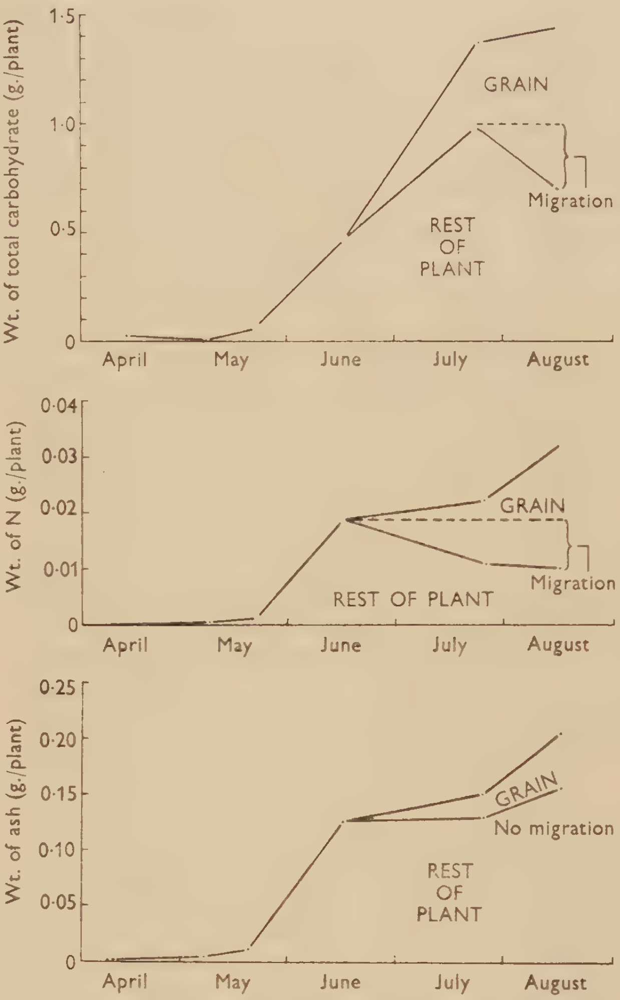

FIG. 4. Evidence for migration of carbohydrate and nitrogen to the developing grain of the oat (Auchincruive, 1949).

Nitrogen apparently begins to move in June and carbohydrate at the end of July; defoliation in early August therefore reduces the amount of tissue from which migration could take place. The relation between degree of defoliation and loss of yield for 10th August in Figure 3D is linear, where the earlier curves are exponential or sigmoidal, and this is quite in keeping with the fact of migration.

Results of studies of the seed weight and composition of barley grain from defoliated plants (Figure 5) are in agreement with, though they do not prove, the migration of nutrients. Relations between defoliation and yield are generally similar to those of the oat, though the early curve (17th May) is exponential, not sigmoidal, and the relations for 11th June and 23rd July are both linear. Seed weight is considerably affected, in contrast to the bean [5]. Solids and ash show no consistent

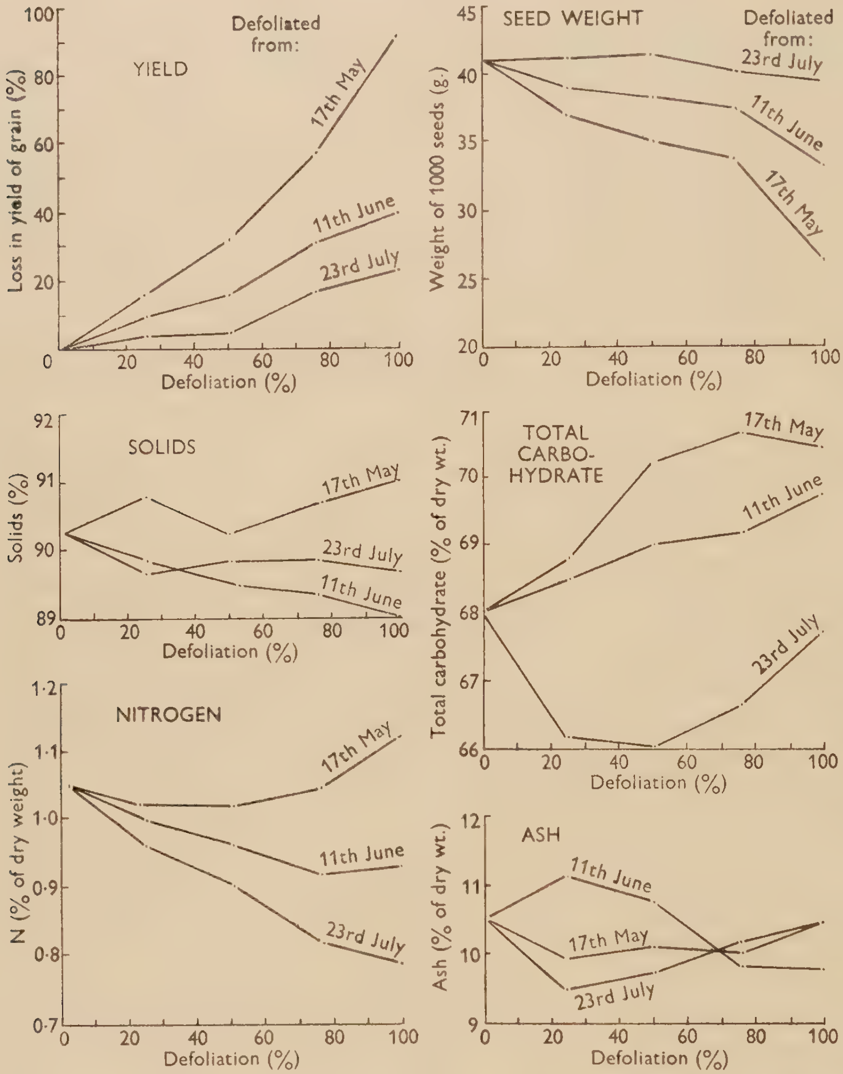

Fig. 5. Relations between defoliation and grain yield for barley (var. Abed Maja) (Auchincruive, 1956), with analytical data for the grain.

relation with defoliation either for degree or time. The ash results differ from those obtained with winter wheat by Miller *et al.* [10], who interpreted their findings on a basis of translocation of ash to the grain; they also stated, however, that increase of ash in the grain was apparently caused by decrease in the amounts of carbohydrate and protein. The present results show small but progressive decreases in the percentages of total carbohydrate and nitrogen from the earliest defoliations (Figure 5). The relative magnitudes of the decreases following defoliations from 23rd July for carbohydrate and from 11th June and 23rd July for nitrogen provide the factors which are in line with migration. There is nothing incongruous about these differences in performance between barley, bean and wheat, for plant species react in different ways and so must be investigated individually if results of practical value are to be obtained.

Effects of Potato Defoliation

The effects on yield of defoliation of the potato (Figure 6) resemble those of barley and oat, but there is little suggestion of a sigmoidal relation showing "wound shock." The defoliation curves beginning 28th May and 25th June are, moreover, very similar for all sizes of tuber; the explanation is probably that between these dates the variety in question (Kerr's Pink) had expended its nutritional capital from the mother tuber and not yet made sufficient of its own to produce tubers. Curves showing relations between defoliation from the early dates and the yield of seed-size tubers are, however, more exponential than are those for ware-size tubers. The potato, being attacked by blight every year, is particularly at the mercy of the defoliation which the disease always brings, and a study of the subject is therefore of particular value on this crop.

If we plot tuber production as a percentage of the maximum crop ultimately to be attained, and compare it with the percentage yield left by 100% defoliation at different dates for the same year, the two curves almost coincide (Figure 7). This confirms that complete defoliation occurring at any time would bring tuber production to an end. Again, if we obtain a blight-free tuber production curve and project on it the times of 100% blight over a period of years (also illustrated by Figure 7), we can calculate the losses of overall yield that would have been occasioned. The figures are found to be very similar to the yields saved by efficient protective spraying. Growth cycle studies also provide evidence that potato tubers continue to increase in weight until the time of 100% foliage destruction by blight, but not after. These

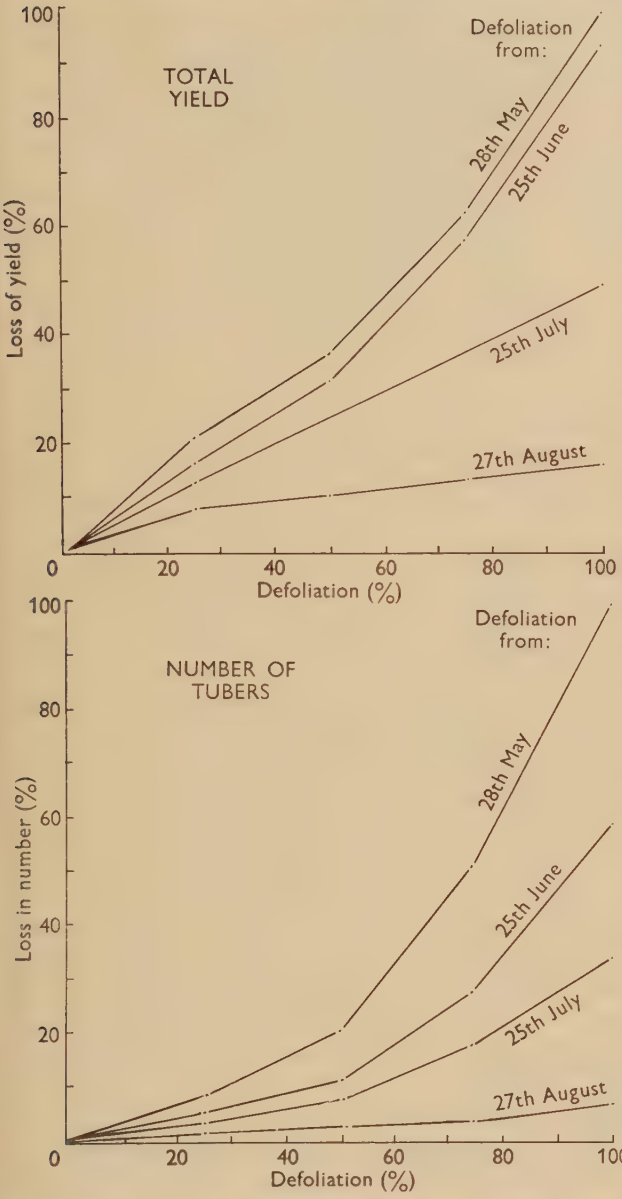

FIG. 6. Relations between defoliation and loss of potato tubers (var. Kerr's Pink) (Auchincruive, 1956).

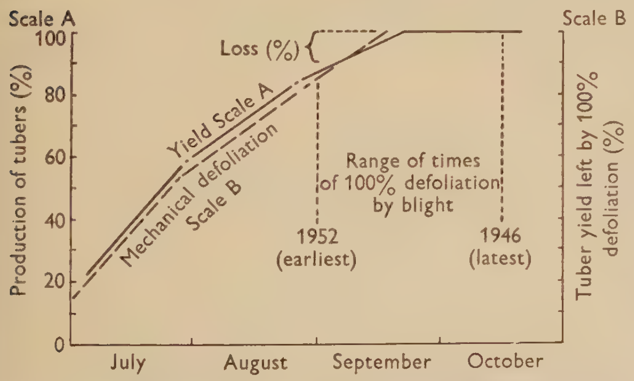

FIG. 7. Potato tuber production cycle compared with the defoliation curve and the range of time of 100% defoliation by blight.

estimations therefore combine to show that mechanical defoliation and destruction of foliage by blight give much the same results. The important stage in practice is 100% defoliation; there is a slight discrepancy, since blight develops on the foliage in an exponential or sigmoidal manner. This discrepancy could of course be calculated from the data of Figure 6, but it is hardly worth doing so. Indeed, Large [8], recognizing that 100% defoliation is not easy to assess unless potatoes are visited frequently, uses a more convenient lower value between 75% and 90%, and records of this value show but little difference from 100%.

The average annual loss of yield from foliage destruction by blight is only about 2% at Auchincruive (Ayrshire), so that protective spraying, which costs roughly 2% of the crop value, is not economic in the area. In other parts of Scotland, however, the tuber production curve is rather later, and in west Perthshire, and probably in the central potato area as a whole, where the loss in yield can be as much as 30%, protective spraying is highly economic. In Dumfriesshire, which occupies an intermediate position, increases from spraying are about 13%.

The farmer uses haulm-destroying agents to control the spread of blight to the tubers. This invariably involves some loss in yield, to which the defoliation results shown in Figure 6 provide an index. When main crops were burned down on 27th August the loss (20%) was very close to that shown for complete defoliation in Figure 6 (16%), and in various parts of the west of Scotland it averaged 11%. This is greater than the loss in yield in Ayrshire and must in the nature of things be justified either by a reduction in tuber blight or by an increase in seed-size tubers, for which haulm destruction is also used. If tubers are to be stored, the factor for loss is 1·0 (Figure 1), i.e. any tuber infected with blight, no matter how slightly, is a loss in store. It therefore becomes important to know the times at which the greatest yields of blight-free tubers or the highest yields of seed-size tubers are to be obtained. Figure 8 shows some determinations of the time of maximum production of seed-size tubers for different varieties. These show considerable variation, from early August for Arran Pilot to after the end of September for Golden Wonder, Gladstone and King Edward. It may be doubted if haulm destruction for seed-size control is usually timed with the precision it demands. Spread of blight to the tubers is linked with the time of appearance of the

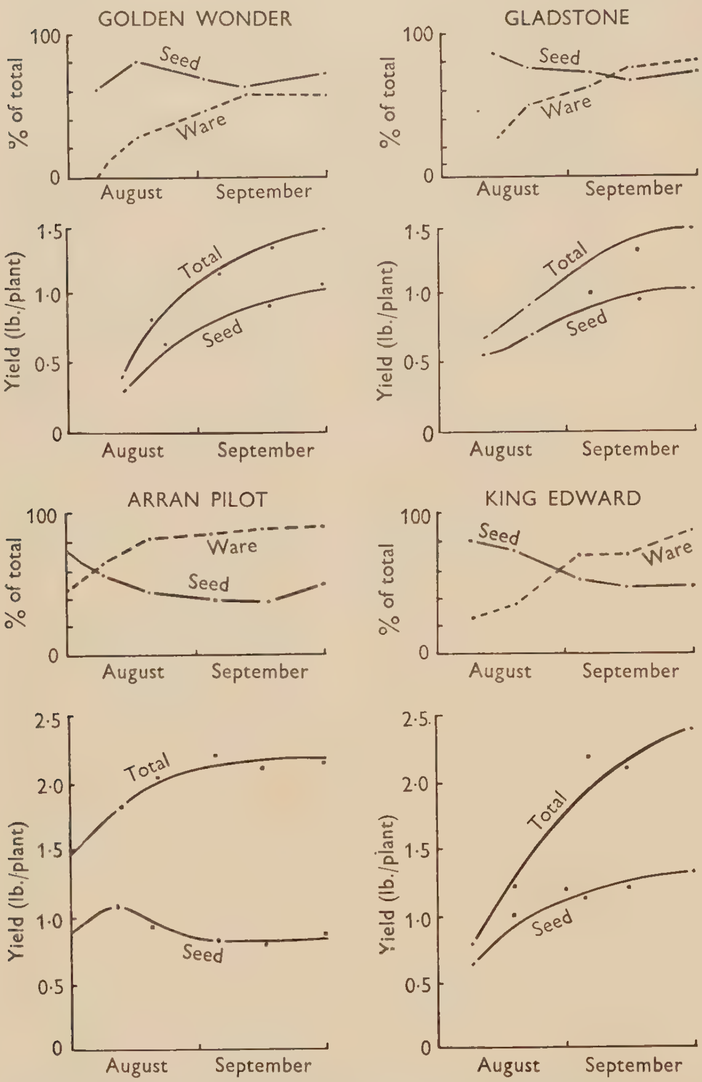

FIG. 8. Times of maximum production of seed-size tubers during August and September (Auchincruive, 1954). Seed size is between 1¼ in. and 2¼ in. riddles (1 in. and 2 in. for Golden Wonder); ware size is over 1¾ in. riddle (1½ in. for Golden Wonder).

disease on the foliage; in most years it occurs at Auchincruive some 7–14 days later, and destructive sprays would have to be so timed if blight-free tubers are required for seed or storage. Such early destruction would involve considerable loss in yield, and more research is necessary to bring precision at this stage.

Another factor which affects the farmer's judgment in planning control measures is that taking a tractor through a well-grown crop causes considerable damage on the rows between the wheels [9]. Damage to the whole crop will depend on the width of the spray boom, and a reasonable approximation can be obtained by dividing the amount of damage shown for a given date in Figure 9 by the number of rows covered by the boom. This value rarely exceeds 5%. The damage is composed of about 15% defoliation on each of four "half" rows, or the equivalent of about 60% on one row. When the yield losses shown against this value for 25th July and 27th August in Figure 6 are plotted on Figure 9, the line joining them is very close to the values obtained by direct experiment. Control measures must bring sufficient advantage to counterbalance this loss.

DURATION AND TIME OF ATTACK

Two kinds of loss must be considered when the effects of a disease outbreak are spread over more than one season. The first is concerned with the persistence of the parasite, and the second with replacement of the host.

Potato root eelworm can persist in the relatively cool Scottish soils for up to thirty years in the absence of potatoes and still produce serious disease at the end. The persistence of wart disease is not known exactly but is probably similar to the eelworm. Clubroot of turnips and swedes is far less persistent in the absence of weed hosts, but these are usually abundant enough for the disease to bridge long rotations. Once the soil is contaminated with such long-persisting organisms the loss recurs indefinitely, and the system of agriculture must be changed either by abandoning the cultivation of susceptible crops or by excluding them for what is usually a *very* long rotation.

Losses in permanent crops are particularly costly. If a tree is killed by a disease or so drastically reduced in yield as to require replacement, the actual loss will depend on the physiological ability of the young tree to regain full production. Figure 10 illustrates this for a

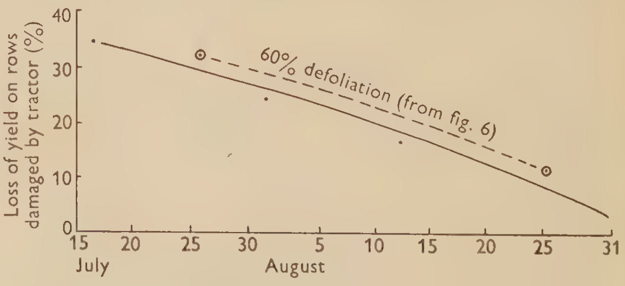

FIG. 9. Total losses from four half-rows of potatoes damaged by taking a four-wheeled tractor through the crop at various times.

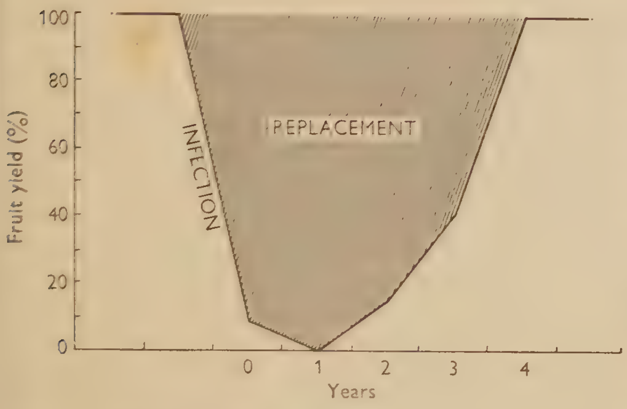

FIG. 10. Regaining maximum yield by replacement of a blackcurrant bush attacked by the reversion virus. The shaded area represents 3·3 years' production.

blackcurrant bush attacked by the virus disease, reversion. In the first full year of infection the yield of each infected bush will fall by about 87% (Figure 1), and, since a return of only 13% of the expected yield would not meet cultivation costs and overhead expenses, the plant must be replaced by a young bush, which will bear no fruit in the first year of establishment. Thereafter its yield will increase until the fourth year, when full production will be attained. The area shaded in Figure 10 is equivalent to a loss of 3·3 years' full production for each tree attacked.

The effects of defoliation on yield are usually greatest in the later stages of growth, and it is well known that many of our more common fungus diseases do not attack until well on in the plant's life. Growth cycle studies throw light on this matter. They show, for instance, that in Scotland chocolate spot of the bean usually begins its main attack in early August, after seed formation has been completed [4]. The disease is, indeed, most severe on the purely vegetative growth made after the grain has been laid down, and it is not therefore surprising that it was found to have no discernible effect on yield in the disease phenology plots at Auchincruive.

It has been found possible to use a physiological interpretation of growth cycle analyses to explain why oats are not attacked by leaf spot (*Helminthosporium*) or potatoes by blight in the earlier stages of growth. There is a variation in the host's physiological ability to permit fungal attack, and this "disease potential" is quite different from genetically controlled resistance or susceptibility. The potential is occasionally high for a time in very young plants, but is always low in mid-growth, and only rises towards the later stages, again permitting attack of the disease. A ratio within the host—the weight of total carbohydrate in the whole plant divided by the residual dry weight of the shoot—varies in a similar way and can be used to determine the disease potential, probably because the ratio gives a measure of the plant's "spare" carbohydrate which may be plundered by a parasite [6, 7]. There can be little doubt that low ratio values and their concomitant low disease potentials during the middle periods of growth safeguard plants from the serious effects of disease defoliation in those stages (Figures 3, 5, 6).

Whether physiology of the host is investigated in the simple way described in the main part of this text or in the complex manner indicated in the last paragraph, it must be combined with study of the parasite to give a complete picture of what happens when a crop is attacked by disease.

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PLANT DISEASES IN THE COLONIES

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There is a general dearth of accurate information on the incidence and economic importance of crop diseases, and only in post-war years have appreciable efforts been made to fill this gap. Knowledge of the kind is of great value not only to plant pathologists but to those who are directly concerned in planning research and development work on a national scale, especially in tropical countries where diseases frequently cause very heavy losses.

There are several reasons why administrative officers and pathologists should know the extent of losses caused by plant diseases not only in the territories under their direct jurisdiction but in other lands as well. Most important, perhaps, is that the limited amount of technical manpower available should be directed as advantageously as possible to the control of those diseases which cause the greatest loss. We should also be able to say what cost is justified in controlling a particular disease, and should know at an early stage in the outbreak of some new disease just how much damage or reduction in the yield of a crop is to be expected if the trouble spreads.

It is always difficult to estimate the losses caused by plant diseases, and especially so in countries where statistics are rudimentary, farms are small, and research workers are few. No standardized system exists for recording and expressing crop losses, and by their varying nature it would be difficult to establish one. This is often disconcertingly obvious. For instance, the damage caused by swollen shoot disease of cocoa in West Africa was expressed in four different ways between 1945 and 1951: in the Gold Coast as a financial (crop value) loss and later as the numbers of infected trees; in Nigeria as the number of trees cut out to prevent further spread and as an annual loss in crop. These several methods of recording the losses make it difficult to assess the progress of the disease and the overall future of the crop in West Africa.

Diseases in different crops operate in a variety of ways and necessitate different methods of assessment. For example, the same method of expression cannot be applied to both an annual crop like wheat in which the returns from one season's harvest are what count and a young plantation of tea, coffee or rubber which must continue to grow for some years before any crop results at all. Again, the assessment of loss of wheat due to rust could not conveniently be upon the same basis as that of potatoes due to a tuber-borne virus, and other methods are required for such very different diseases as blister blight of tea or canker of a timber tree.

It is intended in what follows to show how different are the types of loss in the various kinds of crop—permanent and semi-permanent, vegetatively propagated, and grown from seed—and to provide a brief estimate of losses in Colonial territories of the Commonwealth.

PERMANENT AND SEMI-PERMANENT CROPS

Upon crops of a permanent or semi-permanent nature, the tree crops, depends the livelihood or wealth of many people in Africa and Asia. Examples are rubber, tea, coffee, cocoa, bananas, sisal and citrus. Diseases of these crops may be divided into three classes according as they kill, have a debilitating effect, or cause crop losses without necessarily doing permanent damage.

Tree-killing Diseases

One of the most spectacular examples of diseases which kill plantation trees is swollen shoot of cocoa. This was first reported from the Gold Coast in 1936 by Auckinleck [2], being found in about 3000 acres. By 1941–42 it had spread some 50 miles west and north-east of the original outbreak and was found in one area 150 miles to the west. Urquhart [15] reported it 50 miles still further west and to the north-west, and by 1945–46 [16] it had extended many miles to north and south. Spread was essentially peripheral, possibly at a fairly steady rate. One report [1] shows that the disease in an 8¼-acre farm on which 31% of the trees were infected in 1945 grew in intensity until 92% were diseased in 1951, and the drop in yield was closely proportional. Five years ago when estimates were made it seemed that in Ghana the annual loss of crop might be of the order of about 80,000 tons, or about 10% of the world cocoa crop. The trees take years to grow and become fruitful, and the capital value of the trees destroyed, on a most conservative and perhaps unrealistic basis, was £25 million. New planting has mitigated the losses but not eliminated them.

In the Protectorate of Zanzibar another plantation disease occurs which in its rate of development and spread resembles swollen shoot of cocoa. The islands of Zanzibar and Pemba were replanted extensively with cloves after destruction by a hurricane in 1872, and about 20 years later a disease characterized by sudden wilting of previously healthy-looking trees broke out. It caused much damage in Zanzibar Island, and in 1948 it was estimated that at least half the mature clove trees had died during the previous 10 or 12 years. Surveys [6] revealed that about 2500 outbreaks occurred in 1950. The relation between the number of trees in the initial outbreak (x) and the annual death rate in an outbreak (y) was found to be expressible by the formula $y=3{\cdot}49+0{\cdot}327x$. The average number of trees involved in an outbreak was about 25, and the average death rate was therefore 11–12 trees per outbreak. It was estimated that at some time between 1965 and 1971 the number of trees in Pemba would fall to half what they were in 1930. Of course, as the trees died other plantations were started, so that the rate of death of the clove trees is an overstatement of the crop loss from the Protectorate. The crop in Zanzibar has only undergone a comparatively slow decline and in Pemba has actually increased somewhat in recent years, owing to substantial new planting of cloves. For the two islands taken together the average loss during the years 1946–52 was 2,800,000 lb., worth about £840,000 at 1952 prices; this represents an 11% loss in yield and it fails to take into account the cost of replanting and waiting until the trees become fruitful.

A disease that has lent itself particularly well to examination from a statistical point of view is Panama disease of bananas, caused by *Fusarium oxysporum* var. *cubense*. In Jamaica it was first reported in 1911–12. As treatment required the removal of diseased trees and disinfection of the soil, which was undertaken by the Department of Agriculture, careful records were kept of the number of trees dying. From the low figure of 625 diseased trees in 1912 the number increased to about 54,000 in 1928 [8]. Thereafter records were discontinued in the worst affected area. Ignoring this, the number of diseased trees had increased to nearly 907,000 by 1939, after which recording ceased. Spread and intensity increased in a logarithmic form to an inevitable maximum—the total number of banana trees in the island.

There was a high negative correlation between the incidence of disease and the number of stems exported. Exports fell from 24,600,000 stems in 1930 to 6,800,000 in 1940, by which year treatment had to be abandoned over large areas and more than 40,000 acres had been destroyed.

Debilitating Diseases

The diseases described above are all lethal, but many have a debilitating effect upon trees without necessarily killing them. One of the best instances is witches' broom of cocoa, caused by the fungus *Marasmius perniciosus* Stahel. It attacks the young green tissue, resulting in a shortening of internodes and a proliferation of buds in the leaf axils, giving rise to the broom-like appearance. It also attacks the flower cushions and prevents the formation of normal buds, those which develop at all being distorted and useless. The disease was first discovered in Surinam, spread to British Guiana by 1906, to West Trinidad in 1928, to Tobago in 1939 and to Grenada in 1948. When Stell [11] first reported the disease from Trinidad he mentioned that infection was slight and occurred mainly in trees growing along the margins of streams where humidity was high. Several years later he claimed [12] that out of 130,000 acres affected no loss occurred in at least 100,000 acres. The same author [13] recorded losses on a government estate of 1% of the total crop in 1933 and 2% in 1934. Two years later, however, the figure for the same estate had risen to 6%, and some neighbouring estates were suffering losses of 8–67%, and averaging 33% [14]. This disease, then, which at first seemed unimportant, was found to be capable of causing great damage in the long run. Precise figures on yield are not available, and the picture is confused by the effects of the economic depression of the 1930s on total exports, but the circumstantial evidence is strong that the fall in export of cocoa from Trinidad and Tobago between 1930 and 1940 was, in part at least, due to this disease. In all probability the poor prices received for cocoa at that time discouraged proper attention to the estates and hastened the depredations of witches' broom and its spread. The writer [8] estimated that in the decade following the end of the second world war 10,000 tons of cocoa were being lost each year in Trinidad.

Because of their invidious nature the diseases causing debility in trees are less capable of expression

LOSSES CAUSED BY PLANT DISEASES IN THE MAJOR CROPS OF THE COLONIES, EXPRESSED AS EQUIVALENT AREA LOST AND AS PERCENTAGE LOSS IN PRODUCTION

Crop group	Crop	Crop area (hectares)	Lost area (hectares)	Loss (%)
Cereals	Sorghum	5,250,000	489,180	9·3
	Maize	2,608,674	355,709	13·6
	Millets	1,808,000	89,910	5·0
	Rice	1,034,450	69,060	6·7
	Wheat	273,100	70,485	25·8
	Barley	67,000	7,670	11·4
	Oats	13,000	1,040	8·0
All cereals		11,054,224	1,083,054	9·8
Sugar and starch	Sweet potatoes and yams	1,761,650	84,088	4·8
	Cassava	1,732,000	287,490	16·6
	Sugar-cane	268,000	21,030	7·8
	Potatoes	18,600	4,158	22·4
	Sago	7,000	—	—
All sugar and starch		3,787,250	396,766	10·5
Pulses	Dry beans	250,100	13,680	5·5
	Soybeans	4,000	—	—
	Lentils	1,000	—	—
All pulses		255,100	13,680	5·4
Oilseeds	Groundnuts	1,517,000	125,740	8·3
	Coconuts	369,900	19,030	5·1
	Sesame	217,000	4,880	2·2
	Oil-palms	58,200	1,254	2·2
	Olives	50,000	—	—
	Sunflower	23,000	740	3·2
	Linseed	3,000	160	5·3
All oilseeds		2,238,100	151,804	6·8
Fruits	Bananas	644,600	32,354	5·0
	Vines	33,000	1,980	6·0
	Oranges and tangerines	23,500	970	4·1
	Pineapples	11,500	1,290	11·2
	Dates	5,000	—	—
	Grapefruit	1,900	59	3·1
	Lemons and limes	1,500	129	8·6
All fruits		721,000	36,782	5·1
Stimulants, drugs and spices	Cacao	1,381,000	405,330	29·4
	Coffee	168,700	12,147	7·2
	Tobacco	151,000	35,260	23·4
	Tea	30,800	340	1·1
	Cloves	21,200	2,200	10·4
	Tonka bean	2,800	—	—
	Vanilla	1,000	150	15·0
All stimulants, drugs and spices		1,756,500	455,427	25·9
Fibres and latex	Cotton	1,430,000	396,840	27·8
	Rubber	1,491,700	187,325	12·6
	Sisal and henequen	337,000	2,310	0·7
	Abaca	3,000	450	15·0
All fibres and latex		3,261,700	586,925	18·0
Other crops	Tomatoes	Areas not available		9·5
GRAND TOTAL		23,073,874	2,724,438	11·8

in statistical form than those which actually kill them. Good examples are the leaf spot of banana in Jamaica (*Mycosphaerella musicola* Leach) and coffee rust (*Hemileia vastatrix* B. & Br.). The former is serious enough in Jamaica to justify spraying, estimated [8] to cost £300,000 for half the bananas in the island, and to this must be added, in any assessment of the total loss, the damage caused by the disease where the trees were not sprayed. Coffee rust also requires expensive spraying in most countries where *arabica* coffee is grown.

Some diseases attack only those parts of the crop in which the planter is interested, for example the fruit or the leaf, and have no permanent effects on vigour of the trees. A good example is black pod of cocoa, which occurs in severe form in Nigeria and to a lesser extent in Ghana and in the Caribbean area. According to Hale [3], the annual loss of cocoa from this disease is 50,000 tons, out of which 25,000–40,000 tons is for Ghana alone, but in the opinion of some cocoa experts losses are even more serious in Nigeria. It seems as if this disease may cause as much loss as swollen shoot, namely at least 10% of the world production.

VEGETATIVELY PROPAGATED CROPS

Diseases of crops in this class differ from those of trees and crops propagated from seed in one important characteristic: vegetative propagation of the host enables the pathogens to be carried within the tissues and transferred from one generation to another without the aid of any outside agency. Of particular importance are the virus diseases, some of which are mainly carried in the material used for multiplication. The numerous virus diseases of potatoes are good examples.

In tropical Africa cassava is severely affected by two virus diseases: mosaic and brown streak, both of which greatly reduce the yield. Losses of 10% or more are not uncommon and have been reported from Nyasaland, Nigeria, Uganda and Zanzibar; the loss in the Colonies has been estimated as about 11% of the yield [8]. When vegetatively propagated crops become infected by viruses the diseased plants in most cases cannot overcome infection, and unless steps are taken to root out rigorously all diseased plants the entire population must eventually succumb.

Sugar cane suffers from a number of diseases borne in the setts, of which a recent instance is leaf scald, caused by *Xanthomonas albilineans* (Ashby) Dowson, in British Guiana. It is estimated to cause more than 10% loss.

CROPS GROWN FROM SEED

Considering the multitude of crops grown from seed it is not surprising that there is a great range of diseases, differing in their mode and rapidity of spread, and the damage they cause.

One of the most striking cases of a disease of a seed-sown crop showing rapid spread is maize rust, caused by *Puccinia polysora* Underw. This disease, at one time known only in Central America, was discovered in 1949 in Sierra Leone, and in the three subsequent years it had spread to Ghana, Nigeria and the Cameroons. By 1952 it had extended to Kenya, Zanzibar, Uganda and Tanganyika, and by 1953 to Nyasaland, Mozambique, Southern Rhodesia, Mauritius, Reunion and Madagascar. According to Rhind [9], loss due to the disease in West Africa in 1951 was equal to 40% of the normal grain yield. Its rapid spread is due to the fact that the fungus produces dry spores capable of being blown over vast distances and still causing infection.

In sharp contrast to the spread of maize rust in Africa over a matter of three or four years is the annual occurrence of bacterial blight or black arm of cotton (*Xanthomonas malvacearum* (E. F. Sm.) Dowson) in various cotton-growing countries. A study of work done in Uganda suggests a close relationship between the high infection of black arm in any one year and poor yields. The disease is seed-borne as well as carried in diseased tissues in the field. Its steady spread from plant to plant, and ultimately from plot to plot, is illustrated by the fact that although seed dressings control the initial phases of the disease they cannot altogether prevent its later development if a very small number of the seeds escape the disinfection process. Bulk-scale seed dressing trials carried out in Uganda showed that the greater the area covered by the treatment the less became the damage resulting from the disease, and general adoption of seed treatment has probably increased the yield of cotton in that country by 25% [8]. The value of the crop losses to the growers in 1950–51 was estimated at £3,000,000.

The extent to which an annual crop suffers loss from a disease depends in part upon the stage of development of the crop at which infection first takes place. Hosking [4], who showed this to be so with rosette of groundnuts, found that the average yield per plant in the bunch types increased from 5·7 g. in early sowings to 64·9 g. in late sowings, corresponding figures for the spreading type being 7·9 g. and 27·3 g.

LOSSES IN YIELD OF MAJOR CROPS

From the results of a survey conducted in the Colonies at the request of the Colonial Insecticides, Fungicides and Herbicides Committee the writer [8] was able to estimate losses of the major crops in these territories. The estimates are rough because the plant pathologists taking part in the survey were only requested to classify the diseases into three groups according as losses were: (*a*) 10% or over, (*b*) substantial but under 10%, and (*c*) small or very small.

These three classes were given arbitrary percentage values of 15, 5 and 1 respectively, and this enables the losses to be calculated on a percentage basis for the entire area. In addition the losses are stated in terms of "loss area" as defined by Ordish [7]. To avoid the error of exaggerating losses to the extent that they can exceed 100%, a mathematical correction was made as described elsewhere [8]. Results for the major crops in the Colonies are summarized in the table.

It is difficult to collect enough data on this subject to satisfy the requirements of critical statistics. No matter what statistical methods of analysis are applied they cannot make the end result any more accurate than the original recording of the statistics themselves. Moreover, use had to be made of figures recorded in numerous published articles not intended for a statistical study of this sort.

Nevertheless it does seem possible to detect a common pattern in the development of plant diseases and the losses they cause. Up to a point the increase is logarithmic in lateral spread or intensity. Later on, the rate of increase is modified by natural limitations to expansion resulting from the discontinuous nature of the plantations, from the total area, or from some other factor such as the maturity of the crop. It should be possible, therefore, to forecast the development of a disease to serious proportions, provided sufficient observations are made in the early stages. This is often difficult to do, because the few plant pathologists in many countries are fully occupied with the urgent problems of controlling the obviously important diseases.

Losses can be disastrous. Some cases of the annihilation of the crop are known. Coffee in Ceylon is a classical example. Disease also destroyed *arabica* coffee in British Guiana many years ago, although replanting took place with the inferior *liberica* coffee, unlike Ceylon, where the opportunity was taken to plant with tea. In Jamaica the Gros Michel variety of banana, decimated by Panama disease, was replaced by the more resistant Lacatan—hardly as good a variety and one which is very susceptible to leaf spot. Moore [5] points out how wart disease has influenced the varieties of potatoes grown. Indeed, it is certain that diseases have often played a substantial role in dictating the crop varieties that are grown today.

The estimate given here of the losses due to crop diseases in the British Colonies, admittedly very rough but based on the opinions of a number of plant pathologists considering each crop separately, indicated that the losses may be of the order of about 12%. Sir John Russell [10] pointed out that the figure of 10% is frequently quoted as the loss caused by plant diseases, pests and weeds in the United Kingdom, and that it would probably not be unfair to put the losses in many countries at 20% or more of the healthy crops. Even this figure may be an underestimate for the Colonies.

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THE ACCUMULATION AND ADHESION OF INSECTICIDES ON LEAF SURFACES

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When an insecticide is dusted or sprayed on plants its efficiency depends not only on the inherent toxicity of the chemical but on the form and persistency of the deposit. Many factors determine the fate of the particles that reach the treated surface, and it is essential to have a sound knowledge of the principles at work in developing methods and materials that will ensure the best possible coverage and protection in the field.

It is the aim of spraying and dusting operations that as much as possible of the insecticide used should be deposited evenly on the plants and that it should persist for as long as protection is required. Only a small percentage of the toxic material applied from spraying or dusting machines ever reaches the crop, and special care has to be taken in the design and use of the equipment if a uniform deposit is to be obtained. Of the insecticide which does deposit most is usually lost in the hours or few days immediately following application, so that comparatively little persists to give more lasting protection. It is not surprising therefore that the factors which influence the accumulation and adhesion of insecticides to leaves and other plant surfaces have been much studied in the expectation that more efficient ways of using insecticides could be discovered. The literature is especially extensive since the optimum conditions differ in each particular case.

The fate of a liquid or solid particle moving towards a surface, such as a leaf, depends upon many factors which operate in three well defined stages: before impaction, at the moment of impaction, and after impaction. Those which operate before impaction determine whether the particle hits the surface or is carried past in the stream lines of air moving around the object. At the moment of impaction various properties of the particle and the surface determine whether it is retained whole, shattered and partially retained, or entirely reflected. After deposition the properties of the particle and the leaf surface act together to determine the form which the deposit takes and how much of the primary deposit is retained. The same factors operate in conjunction with weathering to determine the tenacity and insecticidal activity of the deposit.

FACTORS OPERATING BEFORE IMPACTION

When a liquid or solid particle, for example of an insecticide, moves towards an object it may do so through relatively still air, as when it falls under the influence of gravity, but in most cases where insecticides are being applied the air is also moving with the particle. This air movement is produced directly by a fan in the machinery used for the application, or indirectly as a result of the moving cloud of droplets from a hydraulic sprayer drawing in air which moves along with the cloud. It will be shown that this moving air materially affects the speed of the particles and the distance they are carried, especially with small particles which lose momentum very rapidly. Wind and other natural air currents have the same effect [41].

Principles governing Accumulation

Particles moving in an air stream towards an object deposit to varying extents depending on such factors as stream velocity, mass of the particle and size and shape of the object. Deposition may involve: *sedimentation*—in which the particle falls on to the object owing to gravity; *inertia*—in which the particle in the air stream approaching the object has sufficient energy to continue in its path and resist the angular change in direction of the air stream and strike the object instead of being carried around it; or *interception*—where the trajectory of the centre of a relatively large particle does not intersect with the collecting surface but passes so close that the surface of the particle touches the collector. The efficiency "E" with which the particles are collected is the deposit obtained expressed as a fraction of the amount that would have passed the same area had the object not been present. The dynamic catch increases with the size and speed of the particles approaching the surface and varies inversely with the diameter of the obstruction since the divergent acceleration varies inversely as the size of the obstruction [3, 23, 25]. In practice all these methods will be operating simultaneously, especially with insecticide clouds of mixed particle size.

Sedimentation tends to be more important with heavy particles and low air speeds and produces deposition on the upper surfaces only. Coarse particles with higher terminal velocities settle first, but in still air even the aerosol particles must settle unless acted on by some force greater than gravity. Particles under about 0·1 μ diameter are subject to Brownian movement and deposit indiscriminately on all surfaces because their direction of movement changes with bombardment. When the air is not still, as when the leaves are warm relative to the air, the finest particles may not deposit owing to convection currents. It has been observed, for example, that on a sunny day particles less than 20 μ diameter seldom settle on a leaf surface under the influence of gravity alone. If the leaf is cool, on the other hand, the particles may be assisted in depositing by "thermal repulsion"—a force which acts on a particle in a temperature gradient [40].

As the speed of the air carrying the particles increases, impaction and interception become relatively more important and the picture is complicated by the beginning of turbulent deposition. With a flat object like a microscope slide, having its long axis at right angles to the air stream and its surface horizontal, deposition occurs on both surfaces at wind speeds of 9·5 m./sec. In this case the bluff edge of the slide casts a shadow, as it were, on the leading edge of the slide behind it and no particles are deposited there. Further back there is a region of heavier deposit. When the bluff edge is sharpened the deposition is altered in various ways. Where the slides are orientated vertically, with one surface at right angles to the direction of the air current carrying particles, the quantity which collects increases with the wind speed over the range 1·7–9·5 m./sec. The deposition increases over the whole surface and becomes more even but is always greatest at the margins [17]. Essentially the same results have been obtained with vertical discs at right angles to the air stream. With discs 4·25 and 7·0 cm. diameter, air speeds up to 4 miles per hour and drops of 20, 40 or 60 μ diameter the efficiency of collection increased with the size of the drops and the wind speed and was greater on the smaller disc. At 1 mile per hour only light deposits collected and these were confined to the windward side, but at 4 miles per hour there was a light deposit on the leeward side of the larger discs. It was also noted that protuberances from the discs collected droplets more readily than the discs themselves [18].

It is reasonable to suppose that these results will provide a good guide to what happens on leaves, except that leaves are not smooth and flat. In a laboratory experiment with leaves orientated at various angles in a dust stream, more deposited as the angle increased from 0° (vertical and parallel to the dust stream) to 90°, except on the morphological underside where deposition reached a maximum at 45° and declined towards 90°. More deposited on the morphologically under surface than on the upper surface at all angles. Probably when higher deposition occurred on the under surface it was due to turbulence associated with the protruding leaf veins [2].

Under field conditions the situation is even more complicated. With coarse sprays (say 200 μ diameter upwards) the droplet momentum is sufficiently great to ensure that impaction occurs irrespective of the size, shape, curvature, orientation movement or finer surface features of the leaf. But all these are likely to influence the deposition of smaller particles (say up to 100 μ diameter) of lower momentum.

Electrical forces are also said to influence the deposition of particles on leaf surfaces. From a theoretical point of view it is known that when a charged particle is attracted to a leaf or other surface two forces come into play. One is due to the electric field of the charged particle as it approaches a conducting surface. This, the image force of attraction, is given by Coulomb's law for point charges of unlike sign. It is only of importance within 0·1 mm. of the surface. For a 10 μ diameter particle of high charge at 0·1 mm. from the surface the force involved is about equal to gravity. At 0·03 mm. the force will be greater than ten times gravity. The other force is the action of external electric fields upon the electric field of the particles. This "field force" is due to the existence on the surface of the plant of a charge of opposite sign to that on the particles. It can exert an appreciable influence over several centimetres. Curved lines of electric flux develop between the cloud and the plant not unlike the curved lines of magnetic flux around a magnet. It is because of the curved form of these lines that particles from the cloud can move on to all surfaces of the plant [1].

Electrical charges are produced on droplets when they are formed at the nozzles of hydraulic or atomizing sprayers and by impact or splashing on a surface. Rolling drops on surfaces or sliding films of liquid over surfaces also produce charges. For sprays the droplet charge is directly proportional to the spraying pressure and inversely proportional to the electrolyte concentration [38]. It has also been found that the charge on the droplets of aqueous sprays varies considerably with the solute: compared with distilled water the charge was greatly increased by adding two non-ionic surface active agents, whereas an anionic material reduced the charge to a low level; these differences did not appear to be accounted for by differences in atomization [28].

Dust clouds are usually charged by friction as they pass through the dusting machinery. In general, clouds of inorganic materials become positively charged while clouds of organic materials become negatively charged. Many factors, however, influence the development of the charge produced at the nozzle of an ordinary dusting machine, and to get repeatable results it is necessary to fit a special charging nozzle.

Factors operating in Practice to govern Accumulation

Knowledge of the more fundamental kind which has just been considered is essential in designing equipment for applying insecticides and in deciding on techniques of using it. Very often, before the insecticide can reach a leaf, the particles must penetrate between a network of other leaves, twigs and branches. The problem is to get uniform distribution and penetration to the furthest, most sheltered, parts of the tree or crop. Obviously the network of plant parts offers considerable resistance to the movement of the insecticide clouds and their associated air, and this resistance increases with the density and volume of the stand. For large trees or dense crops, comparatively large amounts of energy must be used in getting the spray to the more sheltered and more remote leaves. This energy has to be supplied by the mass and velocity of the particles and of the air moving with the cloud. In high-volume spraying it is the mass of water that contributes the energy on which penetration depends. In low-volume spraying the mass must be made up by a large increase in the volume of air accompanying the insecticide. Thus it has been found that a small-volume application made with an air-assisted spray gave a much higher deposit than a small-volume application by a hydraulic sprayer [27, 32].

In high-volume spraying the bulk of the spray is produced in droplets so large that they impact on the first object in their path. As comparatively little air movement accompanies the spray the smaller droplets soon lose speed, especially when moving upwards against gravity, and the tendency for them to impact as they drift through trees or ground crops is slight. It is therefore necessary to spray crops heavily from above and trees from at least two sides in order to get good penetration and cover. Any leaves which do not accumulate their dose by direct impact may well be coated by the drip and splashes from other leaves.

In low-volume spraying the droplets are much smaller and the optimum size-range varies for different applications. For example, on thin branches and needle-like leaves much smaller droplets can be used than on trees with broad leaves [37]. In the absence of an accompanying air blast these small droplets do not deposit, as has just been explained. In practice, therefore, optimum results are only obtained when a sufficient time is allowed for the air stream to develop to its full extent through the crop being sprayed. The smaller droplets in these sprays penetrate much more readily to leaves remote from the point of application, and a much better cover can be obtained by treatment from one side only than is obtained with high-volume sprays.

In considering the size of the droplets required to give optimum penetration and impaction, it must be remembered that much of their volume may be composed of volatile solvents which will evaporate rapidly from the large surface exposed. The rate of evaporation will be appreciably depressed if the droplet is surrounded by air containing much vapour, and by the presence of relatively non-volatile insecticides, surface active agents, etc. [6, 24]. Appreciable evaporation does occur in the field and materials are often added to sprays to ensure that the droplet volume does not fall below the desired level, or concentrated sprays may be used in the first instance. Besides the solvent many toxic materials, such as BHC and parathion, are sufficiently volatile to be lost in significant amounts before the droplets reach their target on the plants. Temperature, humidity, wind velocity and chemical characteristics all influence the rate of evaporation. When water is the carrier solvent, the size of the spray drops can be increased by adding a hygroscopic substance, such as "Yumidol" (a hexahydric alcohol), to the spray [29].

Insecticidal dusts are much less widely used today than they were twenty years ago. There are various reasons for this, but we are here only concerned with the low accumulation and persistence of dusts. Accumulation seldom exceeds 15–20%

even on dense foliage and is commonly about 10% [1].

The volume of air carrying a dust cloud can be increased until penetration into the crop is satisfactory, but its velocity cannot be usefully increased beyond a certain level because some of the dust particles that do deposit will be shaken off by the intense fluttering of the leaves. Attempts to increase the quantity accumulated have not been very successful. Even if the particle size of the dust is controlled to the most advantageous level there is a tendency for aggregates (of up to 300 particles) to form, and these, which have very different settling characteristics to the unit particles, tend to dominate the deposition. Adding an oil or water spray to the dust cloud has some effect on deposition but is not always successful. The effect of electrostatic charges on deposition will be considered later.

Shape and specific gravity of individual particles will exert effects upon settling of the dust, but these are often masked by the agglomerates which can also cause wide variability in the results. Very small particles do not deposit well whereas large aggregates deposit well but do not adhere. In practice material passing a 325-mesh sieve is often used, i.e. 1–44 μ (smallest diameter). Of this particles less than 10 μ diameter are difficult to precipitate by impaction. Aggregates may form in the bulk dust from the sieved material, especially if a very fine fraction is present. Once in the dust cloud no further aggregates form, but neither do the existing aggregates tend to break up [29]. It seems that an insecticidal dust should be free of particles below 10 μ diameter which cannot be deposited readily and which promote the formation of aggregates.

The insecticidal dust that accumulates on a leaf may consist of separate particles of the toxic material and the carrier, and if these have different specific gravities and particle-size ranges they will tend to fall out in different places. This difficulty is overcome when the toxic material is deposited on the carrier from a volatile solvent.

It remains to consider the part played by electrostatic charges in the accumulation of insecticides by leaves. The effect is negligible where particles above, say, 20–30 μ diameter fall on to leaves or are impacted on to them by a stream of air [28]. Even in circumstances where effects could be expected, conflicting results have been obtained —perhaps because the charge was not specially applied in a controlled manner but resulted, incidentally as it were, from atomization of the liquid or friction of the dust particles at the nozzle. In such circumstances large variations in the charge are liable to occur. When, on the other hand, the particles are ejected through a specially designed nozzle in which a corona discharge around a coaxial wire produces an ionized electric field they become negatively charged by the air ions moving towards the tube wall of the nozzle, and, because they are all charged with the same sign, they do not neutralize each other and maximum field intensity is developed.

When equipment of this type was used to dust bean plants with lead arsenate, twice as much lead was recovered from the leaves dusted with charged as with uncharged dusts. At high atmospheric humidities the advantage of charged over uncharged dusts was less, but even at 100% R.H. some advantage remained. The charge was found to persist when the particles had travelled 33 ft. from the nozzle and the deposit produced was significantly better [1, 14].

To ensure reliable results the particles of insecticide must be especially charged in a manner similar to that described. The electrostatic forces will then improve the deposition and possibly the distribution of the finer particles, and get them to surfaces where it is difficult to produce sufficiently powerful dynamical forces to cause deposition. The main work of impacting the particles will, however, always have to be done by dynamical forces, and electrostatic effects should be regarded as supplementary. Further work on the subject is no doubt necessary, especially on sprays, but some machines embodying charging nozzles for dusts are now commercially available.

FACTORS OPERATING AT THE TIME OF IMPACTION

Certain leaves are difficult to wet because droplets striking them either land and subsequently roll off or are immediately reflected—i.e. they bounce off the surface.

Reflection is well seen on pea, cereal and iris leaves, but on many other leaves the droplets are retained; whether it will occur depends on the properties of the spray droplet and the surface on which it lands. Certain cases of low spray retention and consequent poor insect control found with low-volume spraying are thought to be due to the reflection of the droplets, so that it is an important practical phenomenon.

Reflection does not occur on smooth surfaces that wet with difficulty, e.g. glass slides treated with silicone, but is seen on slides coated with carbon black or magnesium oxide and on the leaves just mentioned. High-speed photographs show that when the droplets strike the surfaces they are flattened and spread out until they cover an area much larger than they would have done had they been stationary. But on reflecting surfaces the droplet again contracts and bounces away in oscillation. It seems that the kinetic energy of the droplet is transferred to the surface energy of the deformed droplet, which is unstable and retracts violently and overshoots the normal equilibrium position, so that the droplet is again detached [4].

The surfaces on which droplets bounce have a high contact angle with water. No bouncing has been observed from any surface where the advancing contact angle was less than about 140°. Normal spray fluids always show much smaller contact angles than this on smooth surfaces, and it must be assumed that both the high contact angle and bouncing are associated with microroughness of the surface. Probably air is trapped under the droplet on a rough surface. The roughness of the carbon and magnesium oxide films referred to is evident, and recent studies of the surface of pea-leaves with an electron microscope have revealed a fine surface structure which could account for the droplets bouncing.

There is an upper and a lower limit of droplet diameter between which droplets falling at terminal velocity bounce as a whole, the phenomenon being most clearly seen with droplets in the 50–500 μ diameter range [19]. Further, if percentage retention is plotted against decreasing droplet diameter, it is found that there is a critical diameter about which the percentage retention changes very rapidly from a low to a high level. For water drops falling at terminal velocity this is about 100 μ. Very small droplets have too little kinetic energy to overcome the surface energy and viscous changes which occur immediately after impact; large droplets may have so much energy that they shatter. Droplets moving slowly are less likely to bounce or shatter than droplets of the same size moving at a faster rate [4].

Surface tension of the spray fluid has an important influence in determining whether droplets are retained or reflected. Measurements show that retention declines rapidly around a certain critical surface tension. For droplets of diameter 250 μ falling at terminal velocity this is about 45 dynes/cm. [4]. It is satisfactory to measure the surface tension by a static technique for pure liquids and simple solutes; but for solutions with more complex molecules, such as surface active agents, a dynamic technique must be used otherwise the results appear to be anomalous. The reason for this is that when a droplet strikes a surface there is not time for the large molecules to reach the extended interface and exert their full effect on lowering the surface tension before the droplet begins to contract prior to bouncing off. The static technique therefore gives a false impression of the effective surface tension when the droplet impacts, whereas the dynamic technique to some extent reproduces the same conditions and gives a much closer measure [33].

Variations in viscosity within the range likely to occur in insecticidal sprays have very little influence on the percentage of impacting droplets which are reflected [4, 19].

The angle at which droplets strike the surface influences the percentage retained. Thus, for 380 μ diameter droplets of acetic acid-water mixtures falling on pea leaves at terminal velocity, the percentage retained at a surface tension of 46·5 dynes/cm. declined from 38% to 1% for angles between 0° and 60°, and at a surface tension of 42·5 dynes/cm. from 95% to 59% over the same angle range [4, 19].

Investigations of this kind, which give an understanding of the principles that determine whether a droplet which impacts upon a leaf is retained or reflected, are of fundamental importance in designing spray equipment and in formulating sprays to ensure the maximum accumulation of insecticidal material.

FACTORS OPERATING AFTER IMPACTION

After a solid or liquid insecticide particle has landed on a plant surface many other factors come into operation and determine its immediate effect, how long it persists and its insecticidal activity at any stage.

The amount of deposit collected on leaves at the time of application is referred to as the *initial retention*. Its long-term adherence is the *tenacity*, defined as the ratio of the amount of a residue at a given time to its initial retention.

Distribution and coverage must also be considered. The deposit may entirely cover the leaves yet be unevenly distributed [27]. It is unlikely to be uniformly distributed over the whole surface, but a fairly even distribution of scattered drops which leave much of the surface uncovered is commonly seen after dusting or low-volume spraying. The degree of cover required will depend on the insect to be controlled: it can be low for active insects but must be high for small inactive insects; for both, however, a good general distribution will be necessary. If the insecticide has fumigant or systemic properties the standard of distribution and cover can be somewhat relaxed.

The subsequent fate of the insecticide which is retained on the leaf in all types of deposit will also vary. It may remain on the surface or dissolve in the wax and cuticular layers of the leaf or penetrate into the interior and either remain there or be translocated to other parts of the plant.

Initial Retention of Dusts and Sprays

The adhesion of one solid to another occurs when two very smooth, very clean, surfaces come into close contact. It depends on molecular forces and the bond may be very strong. Usually, however, surfaces have molecular films absorbed on them and are micro-rough, so that the actual area of close contact is much less than the apparent area. Adhesion occurs most readily when one of the solids is very thin, since it can bend and touch its neighbour at many more points. The high tenacity of smaller particles is probably due to their deformability and to their greater relative surface area and consequently greater relative surface forces per unit weight as compared with larger particles [16, 36]. These remarks will apply particularly to small flat particles.

The situation in relation to deposits from sprays is much more complex than in the case of dusts. For example, the treatment may be by a high-volume type in which the spray is applied to run-off, or by a low-volume type in which discrete droplets are deposited and no run-off occurs. The spray itself may be a simple solution, a suspension of a solid, an emulsion, or various combinations of these.

High-volume spraying is very wasteful in material and labour, including the labour necessary for carting large volumes of water. The low-volume technique deposits as efficiently if the spray is adequately blast-assisted, and there is no run-off. With both methods there is a variable loss of material as drift.

With high-volume sprays the initial cover may be complete and the deposit uniform; but, owing to drainage of the spray to the leaf margins and contraction of the liquid film on drying, the final deposit may be very uneven. It has been estimated that where the deposit is uniform about 1 gal./acre of a non-volatile oil will give a continuous film [4]. Field experiments have shown that the optimum droplet size expressed in mass median diameter (the mass median diameter divides the spray into two equal masses) for coverage by a ground sprayer, without blast assistance, is from 150 μ down to 80 μ provided that there is no drift problem. Aircraft applications from 5–25 ft. require droplets with mass median diameter of 100–200 μ [31].

With low-volume sprays the droplets remain where they are deposited and evaporate. As the droplets are made finer the cover becomes more even, but with the same air blast fewer are deposited. Apart from this, loss of insecticide from the smaller droplets is likely to be greater owing to more rapid vaporization, decomposition (including decomposition by light), weathering and absorption into the leaf.

Some indication of the increase in cover that may be expected from a decrease in particle size is shown in the table. The calculation is for 100% deposition of droplets from a spray applied at 1 gal./acre. All the droplets are of one size with a contact angle of 90° and there is no coincidence of droplets [31].

THE RELATIONSHIP BETWEEN DROPLET SIZE AND COVER

Droplet diameter μ	No. of droplets per cm.^{2}	Mean distance apart, cm.	Fraction of area covered
10	213,500	0·00216	0·266
20	26,700	0·00615	0·133
40	3,335	0·0173	0·0665
100	213·5	0·0685	0·0266
500	1·71	0·708	0·00532

In practice, with blast-assisted sprayers, the optimum range of droplet diameter for application from ground equipment is probably 30–80 μ, and for application from aircraft 70–100 μ.

Spreading and Wetting Power

The ultimate cover also depends on the spreading and wetting properties of the spray for the surface concerned. *Spreading power* is the ability of the liquid to form a liquid-solid interface and can be measured in terms of the area covered. This is determined by the advancing contact angle, but in solutions of similar advancing contact angles it has been found to be greater if the substances have molecules of long-chain structure. The rate of spreading of a liquid on a plane solid surface is slow, and on leaves it may be influenced by the micro-roughness of the surface and a capillary effect in small channels. *Wetting power* is the ability of the liquid to form a persistent liquid-solid interface after the excess of the spray has been drained off. It is therefore highly correlated with the receding contact angle of the droplet. When the angle is zero wetting is perfect. Even monomolecular layers of impurities on a surface have large effects on the contact angles, and in the case of leaves the advancing angle is always greater than the receding angle [9, 33].

Both wetting and spreading ultimately depend on the attraction between the molecules of the liquid and the chemical groups exposed on the surface of the solid. The effect of roughness depends on the ease with which the surface is wetted: if it is readily wetted, slight roughness reduces the contact angle; if it is not, the surface under the droplet is not completely wetted because air is retained and the contact angle is increased [5, 12].

Many leaves and insects are difficult to wet. For this reason it is advantageous to use a spray with good wetting properties, and notable increases in insecticidal efficiency have been obtained merely by incorporating a wetting agent. This effect, which is due to the insecticide coming into more intimate contact with the insect, may permit a lower dose of insecticide to be used. Some surface active agents have themselves valuable insecticidal properties [33].

Surface active agents may also increase the quantity of material deposited on the sprayed surface by lowering the surface tension and so reducing the percentage of droplets reflected, or by decreasing the contact angle of the droplet on the surface and so preventing it rolling off, or as a result of specific molecular attraction. Most results, however, indicate that lowering the surface tension of the spray reduces the deposit. One reason for this is increased run-off; others will become apparent in the course of the following discussion. In general, it seems that for maximum retention the surface tension of a spray should be such as to give an intermediate angle of contact with the surface concerned.

The contact angle of water on a leaf surface is not a fixed value. It varies with the position on one surface and is commonly different on upper and lower surfaces and on leaves from different parts of the plant. There may also be diurnal fluctuations of as much as 30° in the contact angle due to alternations in the packing of the surface structure of the leaf resulting from changes in turgidity [5, 12].

Deposition from Solutions and Suspensions

Although an insecticide may exert its action the moment the droplet contacts the insect, the more important part of its action usually occurs after it has separated from the carrier. In low-volume sprays separation in the discrete droplets ultimately depends on the evaporation (or possibly penetration into the leaf) of the carrier, but in high-volume sprays applied to run-off much of the carrier drains away leaving only a thin film to evaporate. Besides loss of the carrier, when the droplets of suspensions or emulsions strike a leaf the solid or oil they contain should be deposited. With low-volume sprays this is not important, since the entire droplet evaporates *in situ*; but with high-volume sprays, unless the suspension or emulsion breaks on impact, most of the active material will be lost in the run-off.

With simple solutions, where no deposition of insecticide occurs as a result of the droplet striking the leaf, spraying beyond run-off is wasteful. This is less obvious with emulsions and suspensions, but it has been shown that the quantity of material accumulated on the foliage is not increased by spraying beyond the run-off stage, except with certain solid-oil emulsion sprays [35].

Comparatively little work seems to have been published on deposition of insecticides from suspensions. It has been shown, however, that when they are sprayed on to a surface there is little or no evidence that the solid is preferentially held. It is also known that the initial retention of the suspension is usually greater than that of the aqueous phase alone owing to the effect of the solid in reducing the surface tension of the spray [10].

Deposition from Emulsions

In contrast, much work has been published on factors affecting the stability of emulsions. The oil droplets in emulsions are usually between 0·2 μ and 50 μ in diameter, so that initially they may be larger than many of the droplets which leave the spray nozzle. As a result of spraying, the surface area of the spray fluid is greatly increased and surface active materials will move to the new surfaces, thus lowering the stability of the emulsions.

Opposing this is the evaporation of the droplet which has the effect of concentrating the surface active agent. Later, when the spray droplet lands, the great affinity of the oil for the leaf surface exerts a strong effect on breaking the emulsion.

For insecticidal emulsions containing oil and water, two factors finally determine the initial retention of oil on a given surface: (1) the amount of oil present in the emulsion retained on the surface and which is only deposited after the water has evaporated; (2) the amount of free oil formed and retained as a film when the drops strike a surface [11]. Various properties of the emulsion affect both factors, but it is difficult to separate the effect they have on retention of the emulsion and deposition of the oil.

The oil deposition is less when powerful wetting and spreading agents are used as emulsifiers than when weaker agents (e.g. gum arabic and casein) are employed. It is in fact largely determined by the stability of the emulsion and the wetting power of the external phase. Thus emulsions containing large droplets and those which are unstable owing to their composition give better deposits than more stable emulsions. If the emulsion droplets impact on a surface with high energy this also increases deposition, since the interfacial film surrounding the droplets is more liable to be broken.

In practically all oil-in-water emulsions the particles carry an electric charge. The intensity of the charge and the zeta potential as determined by measurements of electrophoresis are important factors in the stability of emulsions. Deposition is facilitated if cationic emulsifiers are used, since the particles become positively charged and wet foliage is usually negatively charged [33, 34].

Other factors influence the initial retention. For example, the quantity retained on the leaves can be increased by increasing the viscosity of the spray so that less drains off [39]. The properties of the surface also influence the initial deposit by their effects on the volume of the spray held and the breaking of the emulsion. Surfaces that are easily wetted may hold less spray. Roughness of the surface and the presence of hairs may also influence retention. Differences in the affinity of the surface for the oil in the emulsion will affect deposition; this is seen, for example, where the emulsion runs off one leaf and deposits on another unsprayed leaf because the absorption forces on the unoiled surface are different.

The problem with emulsions is to formulate them so that they are stable in the tank but break and deposit their insecticide on striking the foliage. Early mayonnaise types of emulsions deposited only about 10% of their oil. Tank-mix sprays, in which small amounts of emulsifiers are added to the water phase in the spray tank, are quick breaking and deposit 30–40%; so do emulsifiable oils. By adding suitable electrolytes to the water phase the deposit of oil can be increased up to 60% [26].

Tenacity of the Initial Deposit

Tenacity of the initial deposit is defined as the ratio of amount of a residue at a given time to its initial level. It is determined by the physical and chemical properties of the spray and of the surface and the type of weathering to which the deposit is exposed.

The insecticide in a dust which settles on leaves often shows a surprising tenacity, though the quantity accumulated initially is low in comparison with sprays. Much of the material which does deposit on a leaf from a dust blower is liable to be blown or shaken off by the continued air blast. When the air speed is low the layer of still air adhering to the surface of the leaf may be thick enough to protect the dust particles from being blown off, but as the wind speed increases the layer becomes thinner so that the particles are no longer protected. The tenacity can be increased by adding oil or water to the dust, but this must be done with care so as not to affect the distribution initially.

Electrostatic charges apparently make dusts more resistant to loss by vibration, but not to rainfall. Surfaces vary in their capacity to retain dusts. For example, the tenacity of dusts on hairy beans and tomato leaves is greater than on waxy leaves, such as lettuce [2].

Wind and rain shortly after dusting cause a rapid loss of deposits, but after this initial decline they are far less effective. Their action is mainly mechanical and a combination of the two hardly increases the effect of one acting alone. The action of sunlight is quite different: it hastens evaporation and decomposition of the firmly adherent fraction that resists other forms of weathering as well as of the more loosely adherent material [20].

Material deposited from sprays may be liquid or solid and will usually be a complex of insecticide and other non-volatile ingredients, such as oils, emulsifiers and stickers. As with dusts the insecticide on the leaf may remain on the surface or penetrate to varying degrees. The material that has entered the plant may still be available as an insecticide, notably to insects that consume large areas of leaf and to sap-sucking pests.

Wetting of the leaves by rainfall or heavy dew is the most potent factor affecting the tenacity of the spray deposit. The mechanical action of rainfall is less important than it is with dusts, and much of the effect of rain depends on its solvent and re-emulsifying action. It is found that tenacity is dependent on the ease with which the deposit is wetted and is higher on a surface wetted with difficulty. Materials of low solubility are well retained and the presence of supplements of low solubility in water increases tenacity. Potent surface active agents, especially if present in high concentration, sharply reduce retention. Emulsifiers, such as ammonium oleate, which decompose rapidly after deposition have an advantage in this respect [21].

Tenacity may be improved by reducing the particle size when the deposit is a solid, but this does not always increase the resistance to rainfall. For light deposits tenacity may be determined largely by particle-surface adhesion, whereas for heavier deposits particle-particle cohesion may be the important factor; but the relative strength of the two forces has to be taken into account. The time for which deposits are dried before weathering does not seem to influence their tenacity [30, 36]. Compounds that leave waxy or sticky deposits, such as toxaphene and chlordane, are more tenacious than those that leave crystalline deposits, such as DDT [8].

Tenacity has been found to be the same whether the deposit was discrete drops or any intermediate level up to a continuous film [36], though a deposit of separate drops should offer less surface for weathering than the same amount of insecticide in a continuous film [15]. There is an important difference, however, between the deposits of individual drops from a low-volume spray and the film left by a high-volume spray applied to run off: the individual droplets evaporate and all the emulsifier in the spray is left with the insecticide, whereas when run-off occurs much of the emulsifier may be lost. This difference would be expected to make the low-volume spray deposit more liable to be washed off by rain.

Wind is the second most important weathering factor. As for dusts it operates entirely mechanically by bending the leaves and loosening the deposit so that it is blown or shaken off, or the deposit may be dislodged by the leaves scratching against each other or against twigs. Insecticide is also lost by evaporation and by decomposition in sunlight.

The nature of the surface to which the deposit is adhering also affects tenacity. There are large variations between the leaves of different plants in the tenacity with which deposits are held, and in certain cases, such as potato and bean leaves, adherence is greater on the upper than on the lower surface [36].

With deposits from emulsions and wettable powders the rate of loss from leaves due to weathering is very rapid over the first five or six days. Some way of reducing the loss at this stage would be very valuable. After this initial period the rate of decline over the next two months is much less. During the first phase the rate of loss from an emulsion deposit is usually less than from a wettable powder deposit, and also the amount lost is less. During the second phase the rates of loss at the two levels run more or less parallel. No doubt, however, the results will vary enormously with different formulations, plant types and weathering factors.

Stickers

Materials are sometimes added to insecticidal dusts and sprays to increase the tenacity of the deposit. Various oils are used with dusts and a large variety of materials with sprays. Some compounds are said to combine the properties of spreaders and stickers, but in general the better stickers are not good spreaders and vice versa. Oils, such as fish oil, soya bean oil and petroleum oil, are among the best stickers, and as little as $\frac{1}{8}$ lb. of oil per 100 gallons of spray may be effective. Other stickers include calcium caseinate, skim and dried milk, wheat flour, glue, gelatin, resins from sugar, Wyoming bentonite, synthetic and natural rubber emulsions, polymeric organic polysulphides of high molecular weight and many besides [13, 22]. The same sticker is not necessarily the most effective on all surfaces.

Some stickers increase the tenacity of insecticides, such as DDT, without giving a corresponding increase in the insecticidal activity of the deposit [22]. This may be due to the insecticide being locked in the film so that it is not available to the insect. Certain films, however, increase the effective persistence of volatile insecticides, such as lindane and organic-phosphorus compounds. In these films volatilization is decreased by the reduction of the vapour pressure of the insecticide and also because the surface area for evaporation per unit weight is reduced; but the insecticide migrates to the surface slowly and exerts its effect [21].

In the presence of stickers redistribution of insecticide to new growth under the influence of weathering is much reduced, but the importance of this factor is not known. The incorporation of wetting agents in a spray may cause a sticker to lose its effectiveness.

It has been shown that certain systemic insecticides, such as paraoxon and demeton, watered on to the roots of plants reach the wax on the surface of the leaves and are then capable of preventing the eggs of *Pieris brassicae* laid on the leaves from hatching [7].

CONCLUSION

Many complex factors enter into the accumulation and adherence of insecticides on leaves. To understand what happens in any particular case the characteristics of the dust or spray cloud, the way in which the deposit is distributed on the plant, the properties of the plant surface and the type of weathering to which the deposit is exposed all have to be considered.

Apparently conflicting results have been reported following investigations in this field, and this is no doubt often due to failure to take into account all the relevant factors rather than to faulty experimentation. It is clear that much further work will have to be done before the subject is fully understood and the most efficient materials and methods are developed for all circumstances.

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JOHNE'S DISEASE IN BRITAIN

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Johne's disease has long been one of the more serious diseases of cattle in Britain, and in recent years it has increased in economic importance, relative to other infections, and become the subject of intensified research. We have much to learn about this widespread disease. Practical measures for its control have still to be found, and we need better methods of early diagnosis to provide the basis of a scheme for its eradication.

About a century and a quarter ago a questionnaire was circulated to veterinarians seeking information on the prevalence of various diseases of cattle. One disease mentioned with great regularity in the returns was a fatal or persistent diarrhoea of the adult cow. There is little doubt that this disease, described in 1831 by Farrow [9] and Hales [12], would now be called Johne's disease. Neither of these reports refers to it in terms other than familiar, and it must be concluded that by the 1830s the disease was already well established in Britain.

Although these early writings refer to the disease in cattle, we now know that sheep and goats are also susceptible and that these three species represent the only susceptible animals of economic importance in the Western world. Recent reports in the Russian literature have described extensive outbreaks among camels in the eastern territories of the U.S.S.R. [27]. Isolated cases have been reported in other animals, but there has always been a history of contact, or possible contact, with either cattle or sheep. For example, cases have been recorded in deer kept in parks and zoological gardens [2, 3, 23] and in a llama [1] and a gnu [17] also kept in zoological collections. Less convincingly documented cases have been reported in the pig [34] and the horse [21]; in the meantime, however, it would be better to assume that naturally occurring Johne's disease is confined to ruminants.

DISTRIBUTION

Johne's disease occurs, or has occurred, in almost every country in the world. It is a remarkable fact, however, that in the drier and sunnier parts of countries such as India, Africa, and Australia the disease has failed to spread rapidly from the centres to which it was accidentally introduced. In the wetter and more northern latitudes the story has been very different. Iceland, for example, was free from Johne's disease until 1933, when twenty sheep, some of which were incubating the disease, were imported from Germany for breeding purposes. The sheep were sent to various centres and set up five separate foci of infection from which the disease spread throughout the country and during the next fifteen years caused the death of 75,000–100,000 sheep. On two occasions all the sheep in an area were destroyed in an attempt to stamp out the infection, but the disease reappeared, It is thought that the disease had already spread to cattle, which carried over the infection until the areas were re-stocked with sheep.

It is frequently said that Johne's disease does not occur in Ireland, but this is an oversimplification of the situation: cases do occur, but only, it is claimed, in imported animals or their progeny. Be that as it may, it is probably true to say that the incidence of the disease is very low indeed. In a sample of 100 lymph nodes taken at random from cattle slaughtered at Belfast abattoir Smith [35] failed to find a single Johne's bacillus. In Britain the disease occurs everywhere, and there are no large areas of the mainland known to be free.

INCIDENCE AND ECONOMIC LOSS

No accurate figure of incidence is available. This largely results from two causes: firstly, Johne's disease is not notifiable in Britain; secondly, as there is no known cure, only a small proportion of the cases is brought to the notice of veterinary surgeons in practice. Their daybooks, therefore, which are usually a reliable "barometer," are in this instance of little value.

Various estimates have, however, been made. The best of these have been based on observations made either at slaughterhouses and knackeries or on a random sample of farms in an area. Two good surveys of the latter type have been carried out by Withers [40, 41] in the south of England. From 1950 to 1954 he recorded all losses among the *adult* cattle from approximately 150 dairy herds in the counties of Berkshire, Surrey and Wiltshire. About 4000 cattle were included in the survey. During these years the average loss due to Johne's disease was 0·9% of the total adult stock. If Withers's figures are analysed still further and "total losses" divided into "losses due to disease" and "losses due to other causes" (e.g. poor yield, old age, infertility), about 20% of the losses due to disease resulted from Johne's disease.

During 1951 and 1952 Norval [24] carried out a survey among the cattle slaughtered as casualties in an Edinburgh abattoir. He found that 28% were affected with Johne's disease. About the same time Phillips and Hughes [26] and Peck [25] were carrying out surveys of material received at three knackeries in Wales and one in Devon. It would appear from these surveys that between 20% and 30% of the cattle received in knackeries may be affected with Johne's disease. Peck actually states that "there was no more serious disease than Johne's disease seen in the knackery."

Apart from clinical cases, it is known that quite a high proportion of apparently normal cattle in Britain harbour the Johne's bacillus [29, 35, 37, 38]. It has been recovered in culture from the lymphatic system of up to 17% of graded cattle passing through an abattoir. Considering the small size of the sample of lymphoid tissue taken and the known deficiencies of the cultural method used, the true figure is likely to be considerably higher.

SYMPTOMS

Although Johne's disease is usually referred to as a chronic disease, the transposition from health to extreme emaciation and even death can be very rapid indeed. A cow can be in apparent good health when it drops its calf, yet two or three weeks later be lying in the knacker's yard fit only for dog meat—and not very much of that. A degree of confusion exists between the "incubation period" and the term "chronic disease." An animal infected as a calf may not die until it is five or six years old, but the death may, as stated above, be comparatively sudden. Whether the disease slowly progresses throughout the years or lies more or less dormant and then flares up is simply not known. It is known, however, that in cases of natural infection the incubation period is seldom less than one year and that the majority of deaths occur in cattle between 2½ and 4½ years of age.

The incubative stage is very prolonged. Probably the earliest changes are to be seen in the condition of the coat. This loses the lustrous sheen which is synonymous with good health and becomes lighter in colour, most noticeably in red-coated and Channel Island breeds. At the same time the hairs begin to stand out from the skin instead of lying flat and so produce a rough "staring" coat so characteristic of the disease. These early symptoms may persist or come and go over long periods, but sooner or later the classical symptom of emaciation becomes apparent (Figure 1). Whatever the other symptoms, all animals in which Johne's disease is active become emaciated.

Johne's disease is an enteric infection, and in cattle diarrhoea is almost a constant symptom, although an occasional animal may waste away and die without scouring. During a typical attack of diarrhoea, dung is passed at frequent intervals and without evidence of straining. A stance akin to that of the female during urination is frequently adopted—probably to minimize soiling of the legs with the liquid faeces. Nevertheless the tail and hindquarters do become badly soiled. The faeces are invariably smooth, dark in colour, and have the consistency of paint. They are passed in a steady, unbroken stream (Figure 2), and if dropped on an impervious surface (such as concrete) bubbles will be seen on the surface. These bubbles are said to be characteristic of the disease and are certainly very common. Light or buff-coloured faeces of a watery consistency containing readily visible particulate matter in suspension are never found in Johne's disease. Such faeces are usually associated with overfeeding of concentrates, with other digestive disturbances, or with intestinal parasites.

In sheep and goats emaciation is also seen, but diarrhoea is not such a constant symptom. In sheep mortality would appear to be greatest at lambing time in animals of over two years of age.

CAUSAL ORGANISM

The causal organism is *Mycobacterium johnei*. This is a member of the acid-fast group of bacilli which includes the leprosy bacillus and the various varieties of the tubercle bacillus, from which it cannot with certainty be distinguished on grounds of size, appearance, or staining reaction. In faecal or bowel preparations, however, the Johne's bacilli tend to be found in clumps rather than as single organisms.

M. johnei is distinguished from the other mycobacteria by its failure to grow on artificial media in

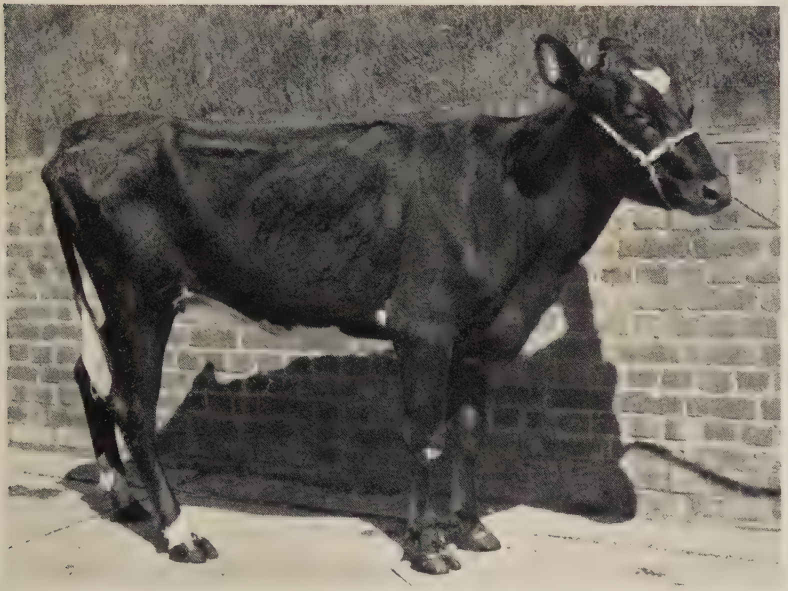

FIG. 1. An advanced case of Johne's disease, showing marked emaciation and consequent prominent skeletal features.

the absence of killed acid-fast bacilli, such as *M. phlei*, or their extracts. This growth-promoting factor has recently been isolated in pure form by a team of workers in England [11]. They extracted very large quantities of *M. phlei* with methanol and after a long fractionation process obtained an amorphous white powder to which they have given the name "Mycobactin." This substance was shown to be responsible for most, if not all, the growth-promoting activity possessed by the *M. phlei*.

The rate of growth of the Johne's bacillus on artificial media is very slow, and on primary isolation it may be 4–8 weeks before colonies are visible to the unaided eye.

No classification based on growth requirements or colony appearance has been made for the bovine strains, but strains isolated from sheep are said to grow even more slowly and may require incubation for six months to a year for a primary growth to appear. A strain isolated from sheep in Scotland is pigmented a brilliant yellow. All strains grow well at temperatures around 38° C and are strictly aerobic. A few have been adapted with difficulty to grow on media that do not contain the accessory growth factor.

PATHOGENESIS AND LESIONS

The pathogenesis of Johne's disease has not yet been studied completely, and there are still wide gaps in our knowledge. For example, it is not known whether the intestinal wall is invaded from the lumen or by way of the lymphatic or the blood stream. The protracted incubation period suggests that the organism does not immediately invade the intestine but spends some considerable time elsewhere. Other mycobacteria have an affinity for the lymphatic system, and there is a certain amount of evidence to suggest that this is also so with *M. johnei*. In an affected animal *M. johnei* can be regularly cultivated from a wide selection of lymph nodes, and Rankin [30] found that in experimental infection the bacillus could be recovered from the lymph nodes before it could be recovered from the intestine. He also found lesions in the hepatic lymph node while the intestine was still normal. Smith [36] obtained a higher recovery rate from the retropharyngeal nodes of apparently healthy cattle than from their mesenteric nodes, suggesting that invasion may be by way of the pharynx.

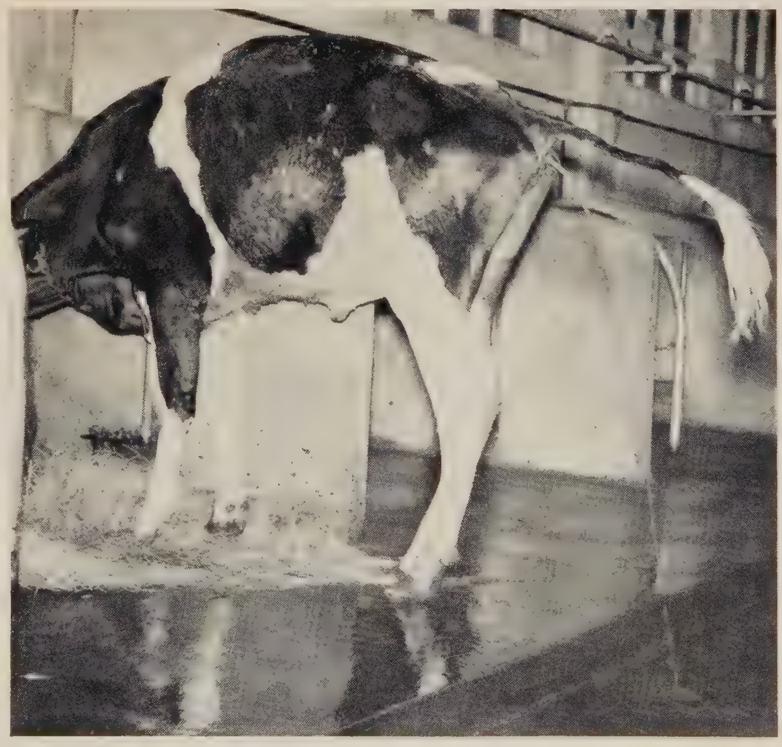

FIG. 2. Johne's disease. Fluid faeces being passed in an unbroken stream.

Sooner or later, however, the intestine becomes affected and lesions develop. These vary from minute clusters of endothelioid cells, requiring the use of microscopic techniques for their demonstration, to a gross invasion of the intestinal mucous membrane by myriads of organisms, resulting in massive proliferation of endothelioid cells with consequent thickening and corrugation of the mucous membrane. Ulceration is not a feature of the disease; nor is haemorrhage in the sense that there is bleeding into the lumen of the intestine; but petechial haemorrhages may be seen on the ridges of the corrugations, giving the mucous membrane a blush-pink to red coloration.

Diagnosis at post-mortem is easy when gross changes like those described above are present, but lesions are not always so marked. Frequently, cases that were quite severe clinically show very mild intestinal lesions when examined post-mortem. In such cases examination of the terminal part of the ileum may show obvious lesions; if not, then portions from the last few feet of the ileum should be taken for histological examination. It is the author's experience that if lesions are not found here they are unlikely to be found further forward in the intestine.

The mesenteric lymph nodes are often swollen and soft, but in cattle the lesion never progresses beyond the infiltrative stage. Death of tissue with the consequent caseation and calcification found in a tuberculous lesion does not occur in cattle, though such lesions have been found in the mesenteric lymph nodes of affected sheep and goats.

DIAGNOSIS

Ante-mortem diagnosis has to be considered under two headings, namely diagnosis of the clinical disease and diagnosis of pre-clinical infection. The various tests for these have different degrees of accuracy.

For diagnosis of the clinical disease the symptoms alone are almost sufficient. The spectacle of an emaciated cow with prominent pelvic, spinal and costal bones, a rough staring coat, the tail and hindquarters liberally plastered with faeces which are being passed in liquid form at frequent intervals, is highly suggestive of Johne's disease. Confirmation of this is best carried out by microscopical examination of the faeces for the presence of acid-fast bacilli, and by means of a complement-fixation test carried out on a sample of serum from the suspect cow. If acid-fast bacilli are found, especially in groups, Johne's disease is confirmed; but their absence does not rule out the possibility of Johne's disease, as the bacilli are not always easy to find.

The complement-fixation test is most accurate in advanced cases of disease (95% accurate) and a positive test in a clinically suspect cow would be confirmatory [4, 13, 14, 32]. On the other hand, a negative test in a scouring cow would suggest that care should be taken to eliminate other possible causes of diarrhoea before making a diagnosis of Johne's disease.

The diagnosis of pre-clinical infection could be the basis of a scheme for the eradication of Johne's disease, but unfortunately no test is accurate enough for this purpose.

It has been generally accepted that the examination of faecal smears from cases not showing diarrhoea is unsatisfactory. The new method of preparing such smears described by Cunningham and Gilmour [5] is certainly an improvement, but more work will have to be done before the true value of this technique can be assessed.

The highly satisfactory results obtained in diagnosing clinical disease using the complement-fixation test have not so far been repeatable in pre-clinical infection. Of 27 apparently normal cattle known to be infected with *M. johnei* only 6 gave a positive C.F. test [32]. On the other hand, on two farms, where it is known that neither the disease nor the organism exist, between 8% and 22% of the cattle were either positive or weakly positive reactors during a series of tests carried out over a three-year period [32]. Another weakness of the test when used in an eradication programme is that an infected animal may be nearly a year old before the test becomes positive [16].

Allergic tests of the tuberculin type have not given much success in either clinical or pre-clinical Johne's disease. It is true that many cattle having the disease do react to avian tuberculin or Johnin, but the reaction tends to be temporary. Many other cattle, not having the disease, also give positive reactions.

CONTROL

Therapy

In the early stages of the disease the diarrhoea can sometimes be controlled by the use of intestinal astringents, but eventually these become ineffective and the disease progresses to its fatal termination.

In recent years some of the antibiotics and chemotherapeutic agents that have proved so successful in the treatment of tuberculosis in man have been tried in Johne's disease. No success has attended their use. Streptomycin [19], isonicotinic acid hydrazide both alone and combined with streptomycin [28, 30], sulfone [18] and the thiosemicarbazones [10], have all been found to be ineffective.

Although a few instances of recovery have been claimed it is still advisable to regard Johne's disease as incurable and fatal.

Vaccination

More than thirty years ago Vallée and Rinjard [39] introduced the method of vaccination that is still in use today. They called it "premunisation," and the immunity depended on the continuous presence of viable *M. johnei* in a situation within the body where it would do no harm. *M. johnei* introduced subcutaneously has consistently failed to produce the disease, and Vallée and Rinjard made use of this knowledge. They suspended a mixture of Johne's bacilli and powdered pumice in liquid paraffin and inoculated this subcutaneously. A local reaction occurred, resulting in a dense fibrous nodule within which the bacilli were imprisoned. They claimed that so long as this nodule persisted, just so long would the animal resist infection.

This vaccine has been used very extensively in France and to some considerable extent experimentally in Britain. There is little doubt that, where the vaccine has been used, the disease has often been greatly reduced in incidence and, in some instances, abolished. Nevertheless it still remains a problem in France.

Widespread use of the vaccine has not been encouraged in Britain because the accurate interpretation of the tuberculin test becomes difficult, and even impossible, when tuberculosis occurs in an animal that has been vaccinated [33]. This disadvantage would not apply to sheep, as these are not normally tuberculin tested. When bovine tuberculosis has been eradicated it *may* be possible to use the vaccine on a national scale. In the meantime a field trial is in progress to ascertain how the vaccine behaves under varying conditions, and what degree of protection can be expected from single and multiple vaccination. The trial is operated through the Animal Health Division of the Ministry of Agriculture, and is open to both attested and non-designate herds.

Hygiene and Husbandry

Dimock [6, 7] believes that effective control can be obtained by attention to hygiene and husbandry and there is a suggestion that, when heavy culling of the less productive cattle in a herd was practised during the war years, the Johne's incidence decreased. On the other hand, Hole [15] has pointed out that the disease can be prevalent on a farm where the hygiene would appear to be above suspicion. Everyone, however, is agreed that whatever other measures are adopted attention to management is an essential adjunct.

M. johnei cannot multiply outside the body, thus the only source of new infection is an affected animal; but it can survive for up to nine months in water or on pasture [21]. These features must be borne in mind when planning a system of hygiene on a farm where Johne's disease is known to exist. The usual method of contracting the infection is thought to be by the consumption of food or water contaminated with infected faeces; intra-uterine infection of the calf, however, is known to occur [20].

Although the open pond, which has long been suspect, is now usually filled in or fenced off, it should be realized that piped water is only clean when it comes out of the pipe. Far too often troughs and receptacles are not cleaned out, and, as they are low enough, cattle can defaecate into them and so create miniature open ponds probably more heavily contaminated than the old discredited ones.

Calves are much more susceptible to experimental infection than adult cattle; indeed, it seems to be extremely difficult to promote disease in a mature animal [31]. It is important, therefore, to keep calves separate for as long as possible from adult stock, which on an infected farm are all suspect. This can usually be done on a dairy farm, but it cuts right across beef-rearing practice, as it precludes the use of nurse cows.

Calves should be removed from the dam at birth and taken to separate calf-rearing premises. They should be permitted colostrum, but this should be drawn by hand or machine only after very thorough cleaning of the udder and teats. Although in severe cases of the disease the organism has been found occasionally in the udder, faecal contamination is the real danger. But intra-uterine infection can occur, and because the congenitally infected calf will be excreting Johne's bacilli in its faeces calves should be placed in individual pens for as long as possible. No calf should be reared if its mother was a clinical case at the time of birth or becomes one within a month or two of parturition.

Calves are not as a rule turned out to grass, and where they are should not be run together with adult cattle. If infected adults have been on a pasture it would not be advisable to run young stock on the same pasture before resting it for a year.

Liming of pastures and the feeding of minerals to stock have been credited with being effective in controlling Johne's disease, but no experimental proof has ever been produced; indeed, it would be very difficult and costly to devise an experiment that would yield a satisfactory answer to such hypotheses.

Strip grazing has been condemned as being conducive to the spread of Johne's disease [8], but again with no experimental evidence to support the supposition. As calves are not usually strip-grazed, and there is no proof that adult cattle have been infected as a result of this practice, the other benefits resulting from this method of management would appear to outweigh this hypothetical disadvantage. To a certain extent the same remarks apply to zero grazing, although there may be a build-up of infection in the yards in which the cattle are confined. Whether this build-up will be sufficient to overcome the natural resistance of the adult cow is not yet known.

CONCLUSION

Johne's disease as found in cattle and sheep in Britain is of increasing economic importance. It is a fatal disease, and no cure has so far been found for it. As the salvage value on the carcass is practically *nil*, the loss due to the disease has increased with the value of the individual animal, even assuming no increase in disease incidence—a doubtful assumption.

The incubation period is protracted, and it may be that the majority of cases of infection occur in calfhood, although symptoms do not usually appear until after the first or second calving.

The available bacteriological and serological tests are not wholly reliable, although they can be useful guides to the presence of the disease, and at present there are serious disadvantages to the use of prophylactic vaccine. Control therefore depends on the prompt removal from the herd of known cases and attention to methods of hygiene and husbandry.

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BOOK REVIEWS

Farming Weather. L. P. Smith. Pp. ix+208, with line and half-tone illustrations. Thomas Nelson & Sons Ltd., Edinburgh. 1958. 15s. net.

Most farmers will agree that their day-to-day activities are affected by the weather. They may be less inclined to acknowledge the fact that the general pattern of their lives is also governed by the weather or, more precisely, the "climate"—the summation and averaging of all the day-to-day changes of weather. Regional variations in farm practices may be partly explained in terms of different soil types, the likes or prejudices of farmers, or a whole complex of cost factors. But here too the real answer rests in local differences of climate. That farmers have not fully appreciated these facts is not surprising, since no one book has spanned adequately the gap between agriculture and meteorology—the no-man's-land between the art and the science. Now, however, we welcome an authoritative book on the subject, written by a recognized expert. L. P. Smith, Head of the Agricultural Branch of the Meteorological Office, has used his long professional experience as a meteorologist and his personal knowledge of the many weather hazards that face farmers in various parts of the world to present a wealth of material on agricultural meteorology which is at once understandable and extremely useful to the practical farmer and the general reader. Thanks to his gift of exposition and a lively style, he has succeeded in conveying much scientific information while retaining the interest of the non-scientist.

The book has three main sections. Part I—"The Weather"—is concerned with those weather elements, sunshine, light, rain, air temperature, soil temperature, humidity, etc., that are significant to the farmer. These are treated systematically, their importance is demonstrated and their inter-relationships are explained.

In Part II—"The Climate"—the author fashions the data and material of the meteorologist and climatologist into a form suitable for the needs of the farmer. In the chapter entitled "Temperature Climate," for instance, the growing season is singled out for attention, and maps of the British Isles are presented which show average dates of the beginning and end of the growing season, based on a threshold temperature value of 42° F. Similarly in the chapter "Rainfall Climate" the author is rightly concerned more with summer rainfall and winter rainfall than annual rainfall, and he proceeds to examine summer rainfall in terms of moisture available for crop growth (and the possible need for irrigation), and winter rainfall in terms of replacing moisture lost during the summer. The seven chapters and thirteen maps which comprise this section are concerned very largely with the climate of the British Isles, but the farmer's viewpoint is maintained throughout.

Finally, in the five chapters of Part III—"The Forecasts"—there is included a useful discussion of the desirability of forecasters knowing the implications of the advice they offer—"the meteorological difference between frost and no frost is very small; the difference to the fruit-grower could be very great"—and for an agreed terminology whereby the farmer can understand the forecast when he reads or hears it.

The farmer unfamiliar with meteorology will certainly learn from this book how to take advantage of the weather and to make more use of the facilities offered by the Meteorological Office. Altogether a most pleasing volume which should find a place on the bookshelf of the weather-minded farmer and in the library of the non-farmer reader.

G. MELVYN HOWE

Tea. T. Eden. Pp. xvi+201, with line and half-tone illustrations. Longmans, Green & Co. Ltd., London. 1958. 35s. net.

Up to the middle of the last century the only source of tea was China, and although the plant had been naturalized in Brazil, Java, Malaya and many other places, the tea made in all these centres was very unsatisfactory. Of that made in Penang it was stated that it had "acquired the property of a nauseating and slightly emetic drug." Indeed, the attempt to create a tea-growing industry in Assam, despite the aid of the Indian Government, almost collapsed in 1847, and it was not until some years later that tea growing seemed likely to form a commercially satisfactory proposition.

Even when tea production could be made to pay, the methods of culture and manufacture needed were so different from those used for other crops that it took many years before a rational system of tea growing was reached. To grow a perennial plant for the continued production of young leaf shoots during the whole of a season or of the whole year was a new problem which has only gradually been solved. Indeed, we may not yet have found the best methods. Processing of the leaf has changed very little in principle, but the actual practice has been revolutionized and has become a matter of large-scale engineering.

The changes in agricultural and processing methods have been so rapid that it is well to have an up-to-date statement of the present position, and the volume under review gives us this from the pen of perhaps the foremost authority on the subject now living. Dr. Eden has had so many years' experience of the tea industry in Ceylon and other countries that any publication to which his name is attached has almost unique authority. His book, therefore, is more than welcome, and it fills a gap which needed to be occupied.

The scope of the book is wide and includes a discussion of the climatic and soil requirements of the crop, methods of planting and pruning and of plucking the leaf, pests and diseases, and the methods employed in manufacture and preparation of tea for the market. A very interesting section deals with the recently developed methods for the vegetative propagation of tea. Perhaps too much is attempted, for the chapters on the chemistry of the tea leaf and of the chemical changes which take place during manufacture are intelligible only to well-informed chemists, and are certainly not likely to be read with profit by the practical planters for whom the book is written. But, taken as a whole, it is a volume which should be in the hands of every grower of tea, for all would be able to gain knowledge of value to them.

Manuring is dealt with in considerable detail, for the crop is now one of the most intensively manured in the world, at any rate in the older tea areas like Assam and Ceylon. Very largely in consequence of this manuring, the yield of made tea per acre has doubled in the last fifty years. So far, the fertilizers used have been chiefly those which supply nitrogen, while those which supply phosphates and potash have been given less prominence. Lately, according to Eden, the need for other elements is being more and more realized and, in Ceylon at least, this is leading to a much wider range of fertilization than has been the case hitherto.

Perhaps the most interesting part of the treatment of tea as an agricultural crop is that dealing with pruning. The methods adopted in the various regions differ considerably, and Eden gives a good account of them. It is doubtful whether we have reached a final conclusion as to the best way of pruning so as to give the largest number of young leaf shoots in the following period. Whether annual pruning as usually practised in Assam or pruning at longer intervals as is generally done in the more tropical regions is the best plan is still under discussion.

The chapters on the pests and blights of tea concentrate on those which are of particular importance in Ceylon and other tropical regions. In the olden days it was the insect and mite pests which attracted most attention, and the most universally serious still are the red spider mite and the *Helopeltis* bug, generally known as mosquito blight, though both are more or less conquered enemies of tea if the plants are treated by the best methods of pruning, plucking and manuring. In recent years, however, the greatest alarm has been caused by the blister blight fungus *Exobasidium vexans*, which, originating in Upper Assam, has now spread to Ceylon and other more tropical regions, where it has caused much trouble, but is now controllable.

On the whole, the book gives an up-to-date account of what is known about tea culture and manufacture, and how the work is actually carried on. Perhaps there is a little tendency to emphasize the special methods employed in Ceylon and other similarly situated regions; but the practices used elsewhere are well treated, and the book can be confidently recommended to those who are now growing tea or are contemplating its introduction into new areas.

H. H. MANN

Nutrition of the Legumes. (Proceedings of the University of Nottingham Fifth Easter School in Agricultural Science, 1958.) Edited by Prof. E. G. Hallsworth. Pp. x +359, with line and half-tone illustrations. Butterworths Scientific Publications, London. 1958. 55s. net. American edition published by Academic Press Inc., N.Y.

The appearance of the published proceedings of the University of Nottingham Easter School in Agricultural Science has become a welcome annual event. The present volume lives fully up to the standard of its predecessors. The subject under discussion, which included the symbiotic aspect of legume nutrition, attracted a particularly wide range of participants, from agronomists to microbiologists.

The inclusion among the contributors of such names as Tutin, Hewitt, Jensen and Nutman is an assurance that the treatment of the subject is at an authoritative level. From the University of Nottingham itself come papers presented by the editor, Professor Hallsworth, and by Dr. Rorison and Messrs. Greenwood and Norton. These deal largely with the mineral nutrition of legumes under experimental conditions. Dutch and Belgian workers describe research in their countries on the nitrogen nutrition and *Rhizobium* symbiosis of legumes. Australian contributors include Professor Vincent, Drs. Swaby and Black, and Dr. Norris, who provides a particularly stimulating paper, though some scientists will need more convincing that the soil calcium requirement for tropical legumes is in general as low as he suggests. Dr. Bond contributes (though strictly outside the field of a symposium on legume nutrition) a fascinating exposition of his unrivalled knowledge of root nodulation in non-leguminous plants. A striking feature of the book is the increasing amount of attention which is being devoted (and not only in Australia) to research on subterranean clover.

The verbatim records of the discussion which followed the presentation of each paper are not as scientifically valuable as the texts themselves, but probably few readers will resist the temptation of looking through them, and if they provide a lightener in an otherwise very solid reading load this may justify the space taken up.

The individual specialist studies making up most of the book, which might have appeared as having little relationship to each other, are bound together in a carefully ordered list of contents, and some coherence is given by an opening paper dealing with the classification of the legumes (Professor Tutin) and a closing one on "The Role of Legumes in Farm Ecology" (Professor Ellison) which is world-wide in its survey.

Such is the rate of increase in knowledge that it would be impossible today to include within a single book every aspect of the nutrition of legumes that has been investigated. But the reader may be assured that the present volume gives a fair picture of the problems that are currently engaging attention in this field, by authors who are themselves in the forefront of the battle.

Editor and publishers are to be congratulated on the speed with which the book has been produced since the conference was held, the fewness of misprints in a text often highly technical, and the pleasing format.

G. B. MASEFIELD

Quality Beef Production. R. A. Barton. Pp. 108, with line and half-tone illustrations. Massey Agricultural College, Palmerston North, N.Z. 1958. 17s. 6d. (N.Z. currency) net.

This book has been written for the New Zealand farmer with the expressed purpose of encouraging better beef production, particularly the production of better-quality carcasses for the export market. Nevertheless it should also prove both interesting and instructive to British farmers, as it shows the type of beef one of their competitors is being encouraged to market and discusses the best methods of producing this type of beef under New Zealand conditions. This is important, as it would seem that, at the present rate of hill pasture improvement, New Zealand farmers may in the future be competing for a bigger share of the British beef market than they can supply at present, and it would be prudent for British farmers to know something about the type of carcass likely to be shipped.

The book is divided into two parts. The first part—a little over half—deals with beef quality and includes sections on growth and development, carcass and meat quality, and New Zealand carcass grading for the export market. These sections contain a wealth of information on carcass and meat quality and explain how most of the factors affecting them are under the control of the farmer and butcher. Most farmers who read these sections should learn a lot about carcass quality and be encouraged to take an intelligent interest in what their cattle look like "on the hook." The account is very readable and in most cases well illustrated, although the photograph on page 19, which is supposed to show kidney fat in a carcass, leaves a lot to the imagination.

Management for more and better beef is discussed in the second part. There are sections on reproduction and fertility, milk production of beef cows, feeding of beef cattle, common diseases, general management, and one entitled "Looking Ahead." The first two deal specifically with single suckled herds and are of interest to those who run such herds in Britain. There is an interesting section on feeding. The final section, "Looking Ahead," has been skimped. For example, there is a half-page photograph of mobile cattle-weighing scale suitable for weighing bulls under performance test, but the important subject of performance testing is dismissed in the text with eight lines. No mention is made of the future possibility of inducing twinning in beef cattle by using hormones. By comparison with the first half of the book this second half is disappointing, the author going into too great a detail on some subjects for a book of this type while on other aspects the information given is very limited. However, the book is well worth reading.

M. A. CARROLL

ABSTRACTS

CROP PRODUCTION

The effect of soil drying on humus decomposition and nitrogen availability. H. F. Birch, *Plant and Soil*, 1958, **10**, 9–31.

Respirometer experiments show that when a dry soil is moistened a characteristic pattern of decomposition occurs in which an initial period of relatively rapid decomposition (Stage 1) falls during a few days, to a slow steady rate (Stage 2). This pattern is repetitive with successive dryings and rewettings and is common to all soils so far investigated. The magnitude of decomposition depends on the percent carbon in the soil and on drying conditions, air-drying being less effective than oven-drying. Decomposition during Stage 1 conforms approximately to a first-order reaction and proportionate amounts of nitrogen are mineralized. A similar pattern of decomposition occurs under field conditions throughout successive wet and dry seasons. Evidence is presented to show that decomposition involves direct microbial attack of the solid organic substrate and that the recurrent pattern of decomposition is due to the state in which the microbial population is left after drying and its subsequent behaviour on rewetting. The rapid decline in the rate of decomposition on rewetting (Stage 1) appears not to involve (*a*) the development of toxic conditions, (*b*) physical changes in the soil (since similar patterns of decomposition also occur with organic material alone or in sand), or (*c*) rapid decomposition of organic material made soluble by drying. The operation and repetition of this pattern of decomposition in the field have important consequences in the run-down of soil carbon and the mineralization of soil nitrogen, particularly where well-defined wet and dry seasons occur. These consequences are discussed in relation to climate and certain agricultural practices.

(*Author's summary.*)

Uptake of phosphorus from P^{32}-labelled superphosphate by field crops. Part II. Comparison of placed and broadcast applications to barley. G. E. G. Mattingly and F. V. Widdowson, *Plant and Soil*, 1958, **10**, 161–75.

In 1953 and 1954 radioactive superphosphate was drilled at 5 lb. P/acre or applied broadcast at 10 lb. P/acre to Herta barley at Rothamsted. In 1955 the superphosphate was drilled at 5 and 10 lb. P/acre and broadcast at 10 and 20 lb. P/acre; the barley variety was Haisa II. The effects of the treatments on grain yield and total phosphorus were small, but the amounts of labelled phosphate taken up varied with the method of application and with the year. In 1953 phosphate uptake in the first 26 days was rapid, and about the same total amounts were taken up from the 5 lb. P/acre drilled superphosphate and the 10 lb. P/acre broadcast. In 1954 both drilled and broadcast superphosphate were taken up slowly, but at all stages less was recovered from the 10 lb. P/acre broadcast than from the 5 lb. P/acre drilled with the seed. In 1955 the rate of uptake from 5 lb. P/acre drilled or 10 lb. P/acre broadcast was intermediate between the 1953 and the 1954 rates; the rate from 10 lb. P/acre drilled or 20 lb. P/acre broadcast was similar to that from half these amounts of superphosphate in 1953. In all years the uptake of soil phosphate during the early stages of growth was increased by drilled or broadcast superphosphate, but at harvest there was less soil phosphate in crops receiving superphosphate than in unmanured plants.

S.F.A.

Effect of prolonged ammonium sulphate treatment on the calcium status of a tea soil. N. G. Gokhale and N. G. Bhattacharyya, *Emp. J. exp. Agric.*, 1958, **26**, 309–13.

The soil calcium status was investigated in three long-term manurial trials at Borbhetta, north-east India. The trials were designed to show the effects of nitrogen, phosphorus, potassium and shade-tree cover, but only those sub-plots which had received varying ammonium sulphate treatments, with and without shade, were sampled. Calcium contents are tabulated for depths 0–9, 9–18, 18–27 and 27–36 in. For every 100 lb. of ammonium sulphate applied per acre the calcium loss from a soil profile of 3 ft. depth was only 22–34 lb. (as calcium carbonate), although the figure generally assumed is 110 lb. A possible explanation is that these tea soils are naturally very deficient in bases.

S.F.A.

Urea-formaldehyde compounds as slow-acting nitrogenous fertilizers. M. I. E. Long and G. W. Winsor, *Rep. Glassh. Crops Res. Inst.*, 1957, 73–84.

Five urea-formaldehyde compounds of the methylene urea type were prepared and compared with hoof and horn for rate of mineralization during incubation in acid and alkaline soils and in pot tests on tomatoes. The results showed that some of these compounds released inorganic nitrogen slowly and fairly steadily, being in this respect greatly superior to hoof and horn, but much more work is required to find the best formulations. Preliminary tests on urea-formaldehyde compounds of the methylene ether type suggested that they might continue mineralization over longer periods of time than the methylene ureas, but it has not yet been established that they are harmless to plant growth under all conditions.

S.F.A.

Urea-formaldehyde fertilizer as a source of nitrogen for cotton and corn. C. E. Scarsbrook, *Proc. Soil Sci. Soc. Amer.*, 1958, **22**, 442–5.

Various formulations of experimental 12-12-12 fertilizer were compared with ammonium nitrate in field trials in Alabama. The 12-12-12 used in 1955 contained 38% of the nitrogen as urea-formaldehyde with an availability index of 20; in 1956 two formulations were used with urea-formaldehyde percentages of 35 and 36 and availability indices of 49 and 57 respectively. Ammonium nitrate produced higher yields of cotton and maize than equivalent rates of nitrogen from fertilizer containing urea-formaldehyde. Nitrogen contents of maize leaf samples and of grain were higher where ammonium nitrate was the source of nitrogen. The residual value of nitrogen on oat forage following cotton was determined; urea-formaldehyde with an availability index of 49 had the greatest residual effect, but the residual effect from ammonium nitrate was greater than from the index-20 material.

S.F.A.

Competition for sulphur in a grass-clover association. T. M. Walker and A. F. R. Adams, *Plant and Soil*, 1958, **9**, 353–66.

A 3 × 3 factorial experiment was carried out on small plots (4 sq. yd) of poor quality permanent grass in New Zealand, Treatments were 0, 20 and 60 lb. N/acre as nitrolime and 0, 5 and 15 lb. S/acre as gypsum. In the absence of added sulphur, grass took up 98% of the total uptake of sulphur, and nitrogen fixation by the clover was negligible. In the absence of fertilizer nitrogen, sulphur stimulated clover growth. At a low rate of application of sulphur, nitrogen fertilizer increased grass growth and clover was suppressed, but this suppression was largely overcome with a higher dressing of sulphur. Since ammonium sulphate has a large excess of sulphur over nitrogen in terms of plant requirements, it would be expected to stimulate clover as well as grass under these conditions. Solubility of gypsum was low in a dry season and residual effects were pronounced. S.F.A.

A comparison of broadcast and wide-row spaced grasses when managed for foggage production. A. L. Gardner, *J. Brit. Grassl. Soc.*, 1958, **13**, 177–86.

A small-plot trial comparing perennial ryegrass, cocksfoot, timothy, and meadow fescue sown broadcast and also in 21 in. rows was conducted at Auchincruive from 1954 to 1957. The cutting treatments were arranged so that measurement could be made of both summer and winter production. Of the four species, cocksfoot was the most suitable for foggage production. Perennial ryegrass suffered severely from winter killing. Timothy and meadow fescue, although persistent, did not yield as much as cocksfoot. Total dry-matter production over three years was higher from the cocksfoot rows than from the broadcast stand. For ryegrass and meadow fescue, broadcasting gave higher yields than row sowing, while timothy showed no significant difference between sowing methods. During the winter all species showed a loss of dry matter. Losses for ryegrass, cocksfoot, timothy and meadow fescue were respectively 34%, 17%, 18% and 24%. Broadcast stands averaged 11% greater loss than the rows. (*Author's summary.*)

Effects of foliage treatments with gibberellin on forage yield of alfalfa, Kentucky bluegrass and winter wheat. W. G. Corns, *Canad. J. Pl. Sci.*, 1958, **38**, 314–9.

Foliage of greenhouse-grown lucerne and Kentucky bluegrass and field-grown Kharkov winter wheat planted in the spring was sprayed with gibberellin solution once or twice before and/or after clipping. The strength of the potassium salt of gibberellic acid solution used on lucerne was 200 p.p.m., on Kentucky bluegrass both 200 and 400 p.p.m., and on the wheat 36 p.p.m. Tables show the effect of treatments on crop yields. On lucerne none of the chemical treatments had any appreciable visible effect and forage yield was not affected. On Kentucky bluegrass the chemical produced visible elongation of both leaves and stems, fresh and dry weights of the grass were increased at first cutting only by treatment prior to first cut, second harvest was unaffected and total fresh weight slightly increased. Treatment with chemical after the first cut also increased total yields. On wheat gibberellin solution caused elongation of stems and leaves and improved yields as compared with controls in crops harvested once at the end of the trial. E.M.A.

CROP PROTECTION

A comparison of high and low volume sprays for control of the bean aphid *Aphis fabae* Scop. on field beans. M. J. Way, R. Bardner, R. van Baer and P. Aitkenhead, *Ann. appl. Biol.*, 1958, **46**, 399–410.

Of seven insecticides tested as high-volume sprays (140 gal./ac.) in field trials at Rothamsted against *Aphis fabae* on spring-sown field beans, the most effective were nicotine (98–99% pure) at 22·4 oz., demeton at 5·6 oz. and demeton-methyl at 11·2 oz. In a second series five insecticides were compared in medium- (60 gal./ac.) and low-volume (10 gal./ac.) sprays. The amount of insecticide remaining on plants after low-volume application was not less than that from medium-volume sprays, and the degree of control was unaffected by spray volume (except with malathion, which was better as a medium-volume spray). Demeton-methyl at 6 oz./ac., compound 4741 (dimethyl-S-(2-propylsulphinylethane) phosphorthiolate) at 3 oz./ac. and fluoroacetamide at 3 oz./ac. kept populations to below 8 aphids/plant, compared with 230/plant for low-volume malathion at 12 oz./ac., 2400/plant with lindane at 6 oz./ac., and 3550/plant in controls sprayed with wetter alone. Seed yields ranged from 4 cwt./ac. on control plots to 27 cwt./ac. on plots sprayed once with systemic insecticides. D.L.

Winter treatment of dormant roses and their relation to blackspot and spider mite control. W. D. McClellan, E. A. Taylor and F. F. Smith, *Phytopathology*, 1958, **48**, 408–10.

Comparisons were made on the rose plot trials at Beltsville, Maryland, on the effects of dormant sprays, ground sprays, pruning, and clean culture (weed and rose-leaf removal and the provision of a sawdust mulch) on the severity of black spot (*Diplocarpon rosae*) and on red spider mite infestation (*Tetranychus telarius*). Pruning to within an inch or two of the bud union in February was the most effective treatment. Dormant sprays with a wide range of fungicides were of little value in eradicating the disease, and the clean culture regime was also ineffective, although, by destroying such weed hosts as *Erigeron canadensis* and *Stellaria media*, spider mite populations were reduced. The successful hard pruning resulted in a smaller number of blooms early in the year, but at the end of the season the number was equal with that of control plants. D.L.

The effect of various methods of breaking resistance on stem rust reaction and content of soluble carbohydrate and nitrogen in wheat leaves. F. R. Forsyth and D. J. Samborski, *Canad. J. Bot.*, 1958, **36**, 717–23.

The resistance of Khapli wheat to 11 strains of *Puccinia graminis* f. *tritici* was broken after treatment with maleic hydrazide at 100 p.p.m., with DDT at 640 p.p.m., by detaching leaves and floating them on water, and by searing the bases of the first leaves with a hot spatula. The last two methods also changed the reaction of other resistant wheat varieties. DDT and searing increased carbohydrate and soluble nitrogen levels; maleic hydrazide caused lesser increases. Insoluble nitrogen decreased after searing and DDT treatment at rates approximately equal to those of control plants. It remained fairly constant in leaves treated with maleic hydrazide. D.L.

Fire blight—apple and pear warning. J. E. Crosse, *Grower*, 1958, **50**, 764–6.

Fire blight, a bacterial disease of apples and pears caused by *Erwinia amylovora*, has been serious for many years in North America and New Zealand. Its occurrence on pears in Kent in 1957 initiated a survey by the National Agricultural Advisory Service, as a result of which eight outbreaks in that county were recorded, together with unconfirmed cases in Hampshire and Cheshire. So far about 1500 trees have been infected, the variety Laxton's Superb being particularly prone. The source of introduction of the disease is not known, but is presumed to be of recent occurrence, and if rigid control measures are carried out there is hope that the disease in Britain may be checked or even eradicated. There is a danger of the disease spreading to apples and to untrimmed hawthorn hedges. D.L.

Experiments on the movement of streptomycin in cherry trees. J. E. Crosse and C. M. E. Garrett, *Ann. appl. Biol.*, 1958, **46**, 310–20.

Although there was widespread and rapid distribution of streptomycin sulphate in the transpiration stream of cherry trees after petiolar injection, immersion of the blades of intact leaves in the antibiotic solution resulted in a much slower rate of translocation. In detached leaves the uptake of streptomycin was progressive with time, and infection with *Pseudomonas mors-prunorum* was reduced. It was concluded that foliar sprays at field concentrations were unlikely to give a suitable systemic distribution of the antibiotic, but that localized activity might be important in the control of bacterial canker. Antibacterial activity detected in fruiting spurs after spraying was probably induced by direct penetration of the antibiotic through the dermal tissues. D.L.

Nutrient absorption and translocation of phosphorus as influenced by the root knot nematode (*Meloidogyne incognita acrita*). A. H. Hunter, *Soil Sci.*, 1958, **86**, 245–50.

In a North Carolinian greenhouse trial the top growth of root-knot-infested tomato plants at the blossom stage was analysed for mineral element changes. The total dry weight of tops was reduced, and chlorosis of the leaves indicated a degree of malnutrition, yet there was no indication of P, N, K, Ca, Mg, Fe or Cu deficiency; indeed, where significant differences in nutrient content did occur, the lower content in each case was in non-infested plants. The rate of P absorption, as indicated by the use of P^{32}, was reduced in infested plants, but the total P content was higher and no decrease in the rate of translocation was noticed. Under the conditions of the experiment, in which the root system was continually bathed by the nutrient solution, the observed detrimental effects of the nematodes on growth could not be attributed to an interference with the absorption or translocation of the mineral elements studied. D.L.

Tolerance of pasture species to dalapon and amitrol. A. Thompson, *Proc.* 11*th N.Z. Weed Control Conf.*, 1958, 96–102.

Dalapon applied at 5 lb./acre in the early spring to rapidly growing ryegrass caused slight initial damage; it was more damaging applied at the same rate in early summer. In further tests ryegrass showed a seasonal susceptibility to dalapon: in a desiccated sward in late summer the chemical caused negligible damage; a midsummer spray caused moderately severe damage; autumn treatments were more damaging than spring applications. Cocksfoot was damaged by dalapon at 5 lb./acre applied in early spring and early summer; it was fairly tolerant at 2½ lb./acre at both times. White clover was damaged initially by early spring and early summer applications of dalapon at 5 lb./acre; recovery was rapid, especially after the late application. Dalapon at 5 lb./acre severely affected Yorkshire fog (*Holcus lanatus*) and browntop (*Agrostis tenuis*); Chewing's fescue (*Festuca rubra* var. *fallax*) was more tolerant. The addition of amino triazole accelerated the effect of dalapon on grasses. Ryegrass and clover drilled into and ryegrass broadcast on to a treated sward suffered no residual effects from 5 lb. dalapon or 2 lb. amitrol per acre. Soil residues damaged clover and ryegrass sown in bare ground a few days after treatment; the emerging seedlings, not the germinating seeds, were affected. R.L.W.

Weed control in sugar cane in Fiji. N. H. Montieth. *Proc.* 11*th N.Z. Weed Control Conf.*, 1958, 80–4.

The butoxy ethanol ester of 2, 4-D, applied pre-emergence at 2·5 lb. a.e. per acre in 30 gal. water, gave satisfactory control of broadleaved weeds in sugar cane. Germination of cane was not affected if the setts were covered during spraying; direct sprayed young emergence shoots showed occasional slight tip withering. 5 lb. dalapon plus 2,4-D ester at 1·4 lb. a.e./acre row gave satisfactory post-emergence grass control for 6 weeks to 8 months. This treatment caused negligible damage to crops over 2 months old at spraying if not more than 5 lb. dalapon per acre row was applied and direct spraying avoided. Para grass on field edges and drains was controlled by dalapon at 5 lb./acre applied 3 times at monthly intervals. Johnson grass was controlled by 2% dalapon applied at weekly intervals for 3 weeks. Monuron gave effective but uneconomic grass control, TCA was effective but damaging, and amino triazole was damaging. The equipment used and cost of application are discussed. R.L.W.

A simplified logarithmic plot sprayer. B. E. Day. *Weeds*, 1958, **6**, 441–6.

A simplified logarithmic sprayer, identical in principle to the Chesterford logarithmic sprayer reported by Pfeiffer *et al.* in 1955, is described. The simplified machine is independently powered, the major component part being a centrifugal pump mounted directly on the shaft of a petrol engine. The pump case is used as the concentrate chamber and the impeller acts as the agitator as well as the power unit to expel the spray. This pump discharges the spray mixture at a constant volume while simultaneously diluting it with liquid drawn from a separate tank; the concentration of the active ingredient decreases in logarithmic proportion to the volume of spray delivered. The sprayer weighs about 35 lb. when empty, and it can be mounted on a tractor, handcart or other suitable vehicle. R.L.W.

ANIMAL HUSBANDRY

The effect of selection for heifer milk yield on the production level of mature cows. A. Robertson and S. S. Khishin, *J. agric. Sci.*, 1958, **50**, 12–16.

Statistical analysis of data published by the Milk Marketing Board of England and Wales showed that the regressions on first lactation of the progeny of 1273 dairy bulls compared with the first lactation of other heifers in the same herd in the same year were close to zero after correction for bias both for increase from first lactation yield to second and for the increase from second lactation to third. Selection on first lactation yield should not, therefore, change the increase of yield with age. S.F.A.

Studies in grazing management. VI. The influence of free- and strip-grazing and of nitrogenous fertilizers on production from dairy cows. R. C. Campling, D. S. MacLusky and W. Holmes, *J. agric. Sci.*, 1958, **51**, 62–9.

The three treatments compared were strip-grazing on heavily fertilized grass swards, continuous free-range grazing on heavily fertilized grass swards, and continuous free-range grazing on grass and clover swards receiving a basic annual application of phosphate and potash only. No supplementary concentrates were fed, but clean oat straw was offered *ad lib.* Two trials were conducted in 1955 and a third in 1956, all at the Hannah Dairy Research Institute. In continuous grazing the intensively fertilized sward gave 55% more cow-days per acre than the grass and clover sward. There was an increase of 10% in cow-days per acre from the strip-grazed sward compared with the continuously grazed intensively fertilized sward, but this difference may be partly due to a difference in stocking rate. The different methods of management had little effect on milk yield and butterfat percentage, daily pattern of grazing behaviour, or botanical composition of the sward. The solids-not-fat content of the milk was low on all treatments; the highest values occurred when the cows were on free-range grazing on the grass and clover sward; there was little difference in the SNF content of milk of the cows when under the two intensive grazing methods. S.F.A.

Investigations into the use of supplements for the control of hypomagnesaemia in dairy cows during the spring grazing period.

C. Line and others, *J. agric. Sci.*, 1958, **51**, 353–60.

The experiment described was carried out on three farms in southern England and was designed to find a practical substitute to daily drenching cows with 2 oz. calcined magnesite for controlling hypomagnesaemia in cows grazing pasture. Details of botanical composition of the swards grazed, their fertilizer treatment and chemical composition, including magnesium content of dry matter as well as blood serum magnesium levels of the test animals are shown. Supplements to grazing of 2 oz. calcined magnesite in 2 lb. dredge corn cubes or 4 lb. dredge corn mix gave adequate protection against the disorder compared with 50 g. calcined magnesite as a drench in water. Daily supplements of 3½–4 lb. linseed cake or 12,500 i.u. vitamin D gave only partial protection. The economics of providing grazing dairy herds with magnesium supplements is discussed. E.M.A.

The effect of feeding two levels of concentrates on the incidence of ketosis in dairy cows. P. S. Blackburn, M. E. Castle and N. H. Strachan, *Brit. Vet. J.*, 1958, **114**, 323.

Ketosis (acetonaemia), though rarely fatal, causes high losses to the dairy farmer by lowered production, off-flavouring of the milk and general loss of condition. The trials described were conducted in a herd where ketosis had been a major problem for the previous two seasons. Twelve Ayrshire cows from 3¼ to 9¾ years old and due to calve from late February to early April were divided into two groups based on age, liveweight, length of previous dry period and date of calving. All were fed 28 lb. grass silage and 8–12 lb. dried grass daily before and after calving. The high level group was fed 252 lb. concentrates per cow as a "steaming-up" ration in the 6 weeks before calving, and the low level group received 126 lb. in the same period. After calving both groups were fed 4 lb. concentrates/10 lb. milk yield. In each group after calving there were five cases of ketosis; one clinically severe, three clinical and one sub-clinical. Mean levels of ketone bodies in the blood were 4·1 and 3·8 mg./100 ml. for the high and low level groups respectively before calving, and 29·7 and 24·8 mg. 8–14 days after parturition. When allowed to graze early growing grasses the mean values of blood ketones for both groups fell progressively from 42·3 to 4·4 mg. in 15–21 days. Two cows allowed to graze 3 days after calving did not develop symptoms of ketosis and blood values were normal. Butter fat and solids-not-fat were very similar in both groups. On an average there was a loss of about 15% of yield in the early part of lactation when the animals were suffering from ketosis. On the rations fed, the level of "steaming-up" before calving had no effect on the incidence and severity of ketosis. The value of fresh spring grass in reducing ketosis was very apparent. F.W.W.

Eradicating foot rot. A. Littlejohn, *Agriculture*, 1958, **65**, 354.

Foot rot can be eradicated, and provided no infected sheep are brought in the flock can remain free indefinitely. The organism cannot survive in the soil more than 14 days, and pastures that have not carried sheep for this time are as safe as those not occupied for years. Infection is through the skin between the claws, and wet weather predisposes by softening the skin. If the foot is well pared the organism is easily killed, and the best agent is probably 10% solution of formalin. Efficient eradication necessitates examination of the feet of every animal and marking the infected. Feet of healthy sheep are simply trimmed to shape, but the infected foot should have all horn separated from the underlying sensitive structures removed: Infected feet should be held in a tin of 10% formalin, as the foot is generally carried after paring and may not be adequately treated in the bath. All sheep, infected and healthy, should be put through the foot bath followed by at least an hour in a dry pen. Re-examination at weekly intervals is essential; after the second inspection it is only necessary to treat marked sheep, but all should go through the foot bath. The number of infected animals will then be very small, and these should if possible be isolated. It is best to dispose of animals resisting 3 or 4 treatments. To guard against breakdowns the flock should be examined not less than one month after the last case appears to be cured. Eradication is tedious and expensive, but if the skilled work is done by the owner or shepherd the cost should not exceed 1s. 7d. to 3s. 3d. per head. The disease could be eradicated if all owners would make the effort. F.W.W.

Studies on bracken poisoning in cattle, Part V. I. Antice Evans, A. J. Thomas, W. C. Evans and C. M. Edwards, *Brit. vet. J.*, 1958, **114**, 253.

The chief symptoms of bracken poisoning in cattle arise from the progressive failure of the blood-forming tissues. It produces a bone marrow lesion closely resembling that produced by X-radiation. There is preliminary dullness and anorexia, with mucosal discharges, fever and petechial haemorrhages, followed in many cases by sloughing of mucous membranes. At this stage prognosis is grave, and cases are nearly always fatal. Field experience puts mortality at 80% or higher. Attempts to prevent development by daily injections of thiamine, vitamin B12, folic acid and leucovorin were unsuccessful. A large part of this article deals with the use of batyl alcohol as a stimulant of bone marrow activity. Work was carried out in experimentally produced bracken poisoning and in the treatment of field cases. Altogether 31 cases, sufficiently acute for positive diagnosis to be made on external symptoms, were treated with batyl alcohol combined with antibiotic therapy, and 23 recovered. In four of the failures it was impossible to apply treatment in time, and in the remaining four prognosis was grave. The authors conclude that experimentally produced disease can be treated successfully provided the circulating blood cells are not below 2000 leucocytes and 50–100,000 platelets per c.mm., and that in field cases the treatment gave a recovery rate of about 80%. F.W.W.

An outbreak of aldrin poisoning in suckling lambs. J. K. L. Pearson, J. R. Todd and S. Baird, *Vet. Rec.*, 1958, **70**, 783–5.

The grave misuse of aldrin by a farmer in Northern Ireland killed 105 out of 107 lambs 5–9 weeks old. The insecticide, formulated for wireworm control (3 lb. technical aldrin/gal.), had been applied undiluted to the muzzles of the animals in a misguided attempt to destroy a virus infection (contagious pustular dermatitis). Deaths occurred in two clearly defined periods: about 45% died within 36 hr. of treatment; no further deaths took place until the fourth day, and on the seventh day only 5 lambs were still alive. The initial symptoms of poisoning were dullness, bleating, inappetence, tetanic spasms, fits, salivation and blindness. Death followed rapidly after loss of control in the limbs. Temperatures were normal and no effects on bowel movement were noticed. A later symptom, appearing in a few animals only, was a tendency to run away and to keep running: one lamb was followed for 2 miles and never caught. Histological examination revealed foci of degeneration in the forebrain, liver and kidney, and lung congestion occurred terminally, although there was no pneumonia or bronchitis. D.L.

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